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**U. S. TRANSIT TRACK
ASSESSMENT AND RESEARCH NEEDS**

E.G. Cunney
P.L. Boyd
J.A. Woods



DECEMBER 1979

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FINAL REPORT

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Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
OFFICE OF TECHNOLOGY DEVELOPMENT AND DEPLOYMENT
Office of Rail and Construction Technology
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*Transportation
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16. Abstract <p>This report covers a study of transit track made as part of the current research effort of the Urban Mass Transportation Administration of the U.S. Department of Transportation. The study was initiated to identify new technology and research tasks that may help increase the performance, reliability and safety of urban rapid transit systems, and to help ensure that track research provides maximum benefits to the transit industry.</p> <p>The report describes track conditions and current practices in track design, construction, maintenance and inspection; potential opportunities for improvements; favorable technology that is available but not commonly used in transit track systems; and research and support tasks to fill identified needs. The report also describes the evaluation of research and support tasks for relative importance, the analysis of their costs and benefits, and a recommended implementation plan for a track research program.</p>					
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PREFACE

This report was prepared by ENSCO, Inc. with assistance by London Transport International, Ltd, under contract No. DOT-TSC-1502 managed by the Transportation Systems Center, Cambridge, Massachusetts. The contract is part of a program to assist transit properties to improve track, that is sponsored by the Office of Rail and Construction Technology, Office of Technology Development and Deployment, Urban Mass Transportation Administration of the U.S. Department of Transportation.

The overall objective of the contract is to help expand and systematize the search for improvements in transit track. This report describes track conditions; current practices in design, construction and maintenance; and opportunities for improvements. It identifies available track technology and new research tasks of value to transit systems, provides evaluations and cost analyses of research and support tasks, and presents recommendations for a track research program.

The guidance and suggestions of Mr. Gerald Saulnier of the Transportation Systems Center, the technical monitor, and of Mr. G.L. Butler of the Urban Mass Transportation Administration, the program manager, were of great help throughout the study. Effective assistance and useful suggestions were provided by Mr. F.J. Cihak of the American Public Transit Association and by members of the Project Liaison Board: Messrs Bill Anido, MDCTA, Raj T. Bharadwaja, MTAB, Homer Chen and Thomas O'Donnell, WMATA, James F. Delaney, PATH, Chester Marczewski, NYCTA, Roy T. Smith, CTA, Charles Stanford, SEPTA, Harry Tietjen, MARTA, and Donald R. Wolfe, PATCO. As Chairman of Track Seminar Workshops, Mr. E. A. Tillman, Associate Vice President of Daniel, Mann, Johnson & Mendenhall and Mr. V. P. Mahon, Director of Power and Way Maintenance, Bay Area Rapid Transit District, California, contributed greatly to the project by their effective work and leadership.

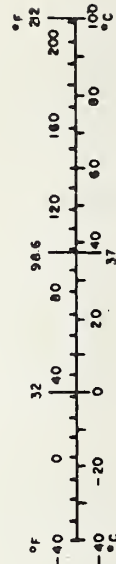
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
m ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
mi	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 cm exactly. For other metric conversions and more detailed tables, see Appendix B, Part 2, pp. 296-298. Units of Length and Mass, Part 2, pp. 296-298.

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1. SUMMARY

1.1 BACKGROUND

Transit track design, construction and maintenance generally follow practices developed in the railroad industry with very good results. Transit track is strong, safe and durable. Improvements are considered necessary, however, to provide a smoother and quieter ride in many cases and to help offset the rising costs of track construction and maintenance in all cases.

A continuing search for improvements in transit track is conducted by the Subcommittee on Track of the Ways and Structures Committee of the American Public Transit Association (APTA). Its members, who represent transit properties,* consulting engineering firms and suppliers, have contributed many of the concepts that are presented as recommendations in this report.

The Transit Track Systems Study described in this report was initiated by the Urban Mass Transportation Administration (UMTA) and the Transportation Systems Center (TSC) to help expand and systematize the current search for improvements in transit track. The study concentrates on identifying new, cost-effective technology in order to accelerate its use in transit track, and on evaluating potential track research tasks in order to estimate the probabilities of their success and the probable values of their products.

1.2 INVESTIGATIONS AND STUDIES

Track problems and practices were investigated at transit properties in the United States, and technology was studied in the transit industry and other industries in the U.S. and

*Including the Toronto Transit Commission (TTC).

Europe. Throughout the study, information was sought on the best technological practices currently available and on improvements that may be obtained through systematic research.

Visits were made to 12 transit properties, and representative samples of existing track were surveyed in detail at eight of them. Information was obtained on track conditions, problems, practices, available track components and tools. Opinions and ideas were collected from transit engineers and others active in track design, construction and maintenance. Track conditions were discussed with representatives of the Federal government, and information was obtained from manufacturers by telephone and mail.

Information on European technology was collected by representatives of London Transport International during visits to five track systems in the United Kingdom and on the Continent. Technology of possible value from outside the transit industry was sought primarily in the railroad industry. Some information on construction and maintenance was taken from airfield and highway practices, and information on maintenance management was taken from plant engineering.

In the literature search, numerous books, reports, technical papers, articles and technical notes were reviewed to obtain information relevant to transit track problems and practices. While most of the literature concerns railroad track, the information presented can sometimes be applied to transit track with allowances for the differences in the operating environment and the traffic. The prior experience of the project engineers in railroad investigations and tests, and in the construction and maintenance of other facilities, was useful in evaluating information in the literature and relating it to transit track conditions.

Valuable ideas and opinions were obtained from leaders in transit track design, construction, maintenance and supply in two workshop sessions at the Transit Track Seminar sponsored by UMTA and TSC on April 25, 1979 in New York City.

1.3 TRACK INVENTORY AND CONDITION

Track inventory data were obtained from the transit properties in a format approved by a Transit Track Systems Study Liaison Board formed by representatives of the transit properties and members of the APTA staff. The data was then summarized to the total quantities of major track components in the U.S., providing a base for broad estimates of trends and requirements.

Track condition was evaluated by observation of the tracks and their performance under traffic, by the survey of representative samples of track, and by discussions of the transit engineers' evaluations of samples and the rest of the revenue track at their respective properties. The track ratings ranged from 95 (excellent) to 53 (very poor). Less than three percent of the track was rated 60 (poor) or below; although this track is safe for low speed traffic, all of it is scheduled for early replacement or removal. The majority of the track was rated in good-to-excellent condition, far exceeding the Federal railroad standards¹ for its traffic speed. Improvements in ride quality are desirable, however, to increase benefits to customers; and improvements in design, construction and maintenance practices are necessary to offset the rising costs of track maintenance and replacement.

¹Federal Track Safety Standards," United States Code, Title 49, Chapter 11, Part 213, October 1971.

1.4 PROBLEMS AND PRACTICES

The problems, practices and opportunities for improvements that were studied were arrived at with the cooperation of the transit industry. They were discussed at meetings of the Project Liaison Board (comprised of representatives of the transit properties and APTA staff) and at a transit track seminar in late April 1979. The seminar included one workshop on design and construction and one on maintenance. The concepts for potential improvements that had been developed during the course of the study were reviewed in these workshops. Changes, deletions and additions were recommended; and priorities were recommended for some of the research tasks that had been identified.

1.4.1 PROBLEMS

Problems that occur in transit track can almost always be predicted and avoided or handled routinely by experienced maintenance managers and skilled track mechanics. In some cases, improvements in maintenance planning and control would be helpful, as well as additional training. In all cases, additional analyses of potential emergencies and damage, and further development of routine procedures for damage control and recovery, would be valuable.

Most of the perceived problems are items in which further improvements would help to offset rising costs or provide smoother and quieter rides for customers. Several areas have been identified in which additional, basic information is needed in order to obtain substantial improvement in track maintenance. These include the wear of rail on curves, corrosion of track components, effective use of guard rails, optimization of time on track for maintenance, and stress transfer between continuous welded rails and long elevated structures.

1.4.2 DESIGN PRACTICES

Transit track design techniques follow railroad practices very closely with some modifications, such as extensive use of guard rails and heavy-duty switch components, to provide higher levels of safety. The designs provide safe and adequate track at reasonable cost. A few opportunities for small improvements were seen, but these would require intensive investigation and would only reduce costs slightly and/or increase the durability of the track.

Transit properties purchase track components in small quantities compared to the relatively large purchases of railroads, and consider the use of available components more economical than ordering the manufacture of small quantities of specially designed track components. Material specifications of the American Railway Engineering Association² (AREA) are used in conjunction with the AREA Portfolio of Trackwork Plans³ for rail and other track components. These specifications appear adequate for transit track requirements with few exceptions, such as turnouts on sharp curves and flangeway gaps at frog points that are not optimum for small diameter wheels.

Data from proprietary designs of manufacturers are used for such items as special trackwork components and direct fixation rail fasteners, based on industry experience with the products. Requirements for inspections and tests are based on AREA specifications, Federal specifications, specifications of engineering societies and institutes, and recommendations of various technical committees.

²Manual of Railway Engineering Practices (Fixed Properties), American Railway Engineering Association (AREA) with revisions through 1977.

³Portfolio of Trackwork Plans, American Railway Engineering Association, Rev. 1973.

1.4.3 CONSTRUCTION PRACTICES

Construction techniques also tend to follow railroad practices. In transit construction, however, there is less use of large equipment because of limited clearances and the relatively small amount of work at any transit construction site. These conditions have also encouraged the prefabrication of track components in order to reduce the work and time required on the construction sites.

In some cases, contractors have successfully employed experienced railroad personnel on a part-time basis in order to overcome shortages of highly skilled track mechanics. In other cases, transit properties have adjusted new track with their own personnel after thorough training under experienced engineers and supervisors.

A few contractors have had difficulty in placing grout pads to accurate line and grade, and they have required excessive numbers of shims to set fasteners at correct elevations. They also have had problems in drilling holes and grouting bolts in correct alignment.

A very effective technique has been developed by engineers of TTC to install fasteners accurately. In this method, lengths of continuous welded rail (CWR) are hauled in and welded together on the concrete slabs, then jacked and blocked accurately into final position. The fasteners are attached to the rails with the bolts hanging into precast pockets in the slabs, and the bolts are grouted in without further adjustment.

1.4.4 MAINTENANCE PRACTICES

As in the cases of design and construction practices, transit maintenance practices resemble those of railroads but on a

smaller scale. In addition there is very strong emphasis on the quick correction of any conditions that could adversely affect safety.

As mentioned earlier, transit track is generally maintained to exceed Federal standards¹ for its speed class. Generally the track is in very good condition for its traffic except for short wavelength rail deviations that contribute to noise and poor ride quality.

Some tendencies were seen towards major replacement of track rather than repetitive adjustment and repair, and maintenance was found to vary greatly. In the best practices, emphasis is placed on preventive maintenance and on correcting deteriorating track conditions routinely and at low cost. The result is that these conditions do not require costly, emergency maintenance as they would if left unattended until they affected safety or operations.

At the lower end of the spectrum of maintenance practices, maintenance work is based on prior years' costs rather than thorough inspection, careful planning and analyses of alternatives. In such cases, emergency maintenance and unit costs are high, and track maintenance crews have lost some of the skills that are apparent in the still-existing work that was done years ago.

The largest potential opportunities for improvements are seen in track maintenance. These involve the application of available industrial engineering techniques to maintenance management in order to achieve systematic planning and control of the work as well as the use of the best available methods, materials, tools and equipment.

¹Standards, p. 3

1.5 ADVANCED TECHNOLOGY

Most of the recent track research in the U.S. has been aimed at improving the thousands of miles of ballasted track operated by the railroads. The results have only minor value to the transit industry, since they usually concern track deterioration caused by very heavy wheel loads or involve large and expensive equipment that would not be cost-effective on short lengths of track.

European research and tests are very often applicable to transit track, as they are oriented to railroads that carry lighter loads than U.S. railroads do. European research, however, often tends towards complicated procedures and devices that are favorable only where the cost of labor is low in relation to materials and energy.

The advances in technology that are most significant to transit track have been in process for many years, but only recently have continuing research and tests made them very reliable and effective. The advances include: continuous welded rail (CWR), direct fixation of rail to concrete slabs and inverts (tunnel floors), floating slabs to reduce vibrations, concrete ties, and rail flaw detection systems. Transit properties are well aware of these developments and are using the products in many cases.

New products that are potentially useful to transit properties with ballasted track are: lime stabilization to strengthen weak subgrades, filter cloths to protect fine soil subbases from the effects of water and vibration, and ballast compaction to increase the stability of ballasted track and reduce its rate of deterioration under traffic.

1.6 POTENTIAL IMPROVEMENTS

More than a hundred potential improvements were discussed during the course of the project. Thirty-five of these are favorable track maintenance practices that are in limited use at some of the transit properties. These favorable practices would be used more widely if maintenance-of-way (M/W) superintendents had more time to investigate them, adapt them to local conditions and overcome local resistance to changes. It was evident that the situation could be improved by providing industrial engineering support to the M/W superintendents. An experienced industrial engineering team could also assist the M/W superintendents to improve the planning and control of routine track maintenance.

Some items that had been suggested as potential improvements were dropped when representatives of the transit industry pointed out that they were not worthwhile; some were found to be included in work already planned or to require information from studies that are underway; and some were found to involve searches for basic information on forces in track in areas being investigated for the railroad industry.

Twenty potential improvements were finally selected for analysis as candidate research or support tasks. One of these tasks, Industrial Engineering Support, is considered to include the 35 favorable maintenance practices mentioned above along with accelerated use of other available technology and technology transfer from other industries.

1.7 ANALYSES

Candidate research and support tasks were analyzed, using life-cycle-cost-analysis procedures in cases where sufficient data were available. In many cases, tasks were evaluated for their overall effects on the productivity of track maintenance organizations and the quality of the maintenance work. In all cases,

the analyses were simplified in order to emphasize the difference in cost/benefits and to clarify necessary assumptions. The costs used are broad, nationwide approximations rather than the detailed estimates that could be developed for a planned project at a single location and specific time, and would be related to local accounting practices and local laws that regulate rate of return and amortization. The broad approximations are sufficient, since the estimated benefits depend in part on predictions of future conditions which, for period beyond five years from the present, cannot be expected to have an overall accuracy much better than $\pm 20\%$.

The potential benefit of an overall improvement to any one property depends on a large number of local factors, one of the most important being the present level of efficiency of the maintenance-of-way organization. Accordingly costs and quantities have been estimated conservatively in an effort to avoid overstating the benefits that may accrue from a candidate research task.

A 50-year life cycle was used in the analyses since a life of over 50 years is indicated for transit track by the condition of the older track systems, the growth of urban areas, and the projected density of use of rapid transit. Exceptions to this are lines for which replacements are already planned. Planning for a system life cycle longer than 50 years is invalidated by high interest rates and uncertainty factors that increase with time.

The analyses of candidate research tasks indicated a very high level of benefits, since many of the improvements will produce cost reductions in track maintenance which costs more than \$60 million per year at present, and they will be repeated year after year throughout the 50-year life cycle of track systems. When the estimated benefits of the 20 most favorable

tasks were discounted to current values (as of the time the tasks are started) at a 10% interest rate, they would found to total \$66 million more than the estimated \$3.6 million cost of the tasks.

The most valuable task by far is the Industrial Engineering Support Task. It is considered probable that this task will result in an improvement in maintenance effectiveness of at least 9%. Larger improvements have been achieved even at facilities that were already very well managed.⁴ The reason is that well qualified maintenance superintendents welcome opportunities for additional improvements (which they would develop themselves if they had additional time) and encourage their people to accept changes that pay benefits.

1.8 PROGRAM IMPLEMENTATION PLAN

As a result of the analyses, 19 of the tasks were recommended for funding under a plan that extends over five fiscal years at an average annual cost of \$720,000. Other tasks were recommended for later consideration, since work on them will depend in part on data collected in earlier tasks. The Industrial Engineering Support Task was divided into five phases, each taking one year and costing an estimated \$250,000. Since this task will accelerate the use of state-of-the-art technology, benefits are expected to begin to accrue within six months of its starting data and to increase at a rapid rate thereafter.

Since new opportunities for improvements are expected to develop, and the relative values of tasks considered in this study are expected to change, the program plan should be reviewed and revised within three years.

⁴"Cost Reduction Through Maintenance Control," Hercules Power Company, 1964

2. BACKGROUND OF TRANSIT TRACK DEVELOPMENT

2.1 TRANSIT DEVELOPMENT

The first rapid transit line in the United States was opened in New York City in 1868⁵ five years after the London Underground had opened with steam locomotives. It was an elevated cable railroad operated by the West Side Elevated Railway Company along Greenwich Street and was later extended on Ninth Avenue to Thirtieth Street. After 1871, the cars were pulled by steam locomotives. Progress was slow at first. Early systems were adaptations of street railroads and commuter railroads, and there was great reliance on the large railroad industry and its suppliers for technical information and track materials.

Electric powered trains were introduced in 1901, and the first regular subway was opened in New York in 1904. Expansion and improvement were rapid from this period until the early 1930's in New York, Boston, Chicago and Philadelphia. At that time, the increased availability of automobiles and buses tended to retard the development of rapid transit and light rail systems in cities with small center cores and growing suburban areas. Improvement of rapid transit stopped almost entirely during the depression years.

After World War II, an awareness developed of the need to improve the quality of inner cities by reducing noise and removing unsightly structures. Increasing emphasis was placed on removing elevated structures and streetcar lines. Until 1970 most of the new construction consisted of subways built to replace elevated and surface transit lines. More recently, projected energy shortages and increasing growth in the cities has led to the development of new rapid transit systems for

⁵"Facts and Figures 1976," New York City Transit Authority.

San Francisco, Washington and Atlanta, and the start of construction for systems in Baltimore and Miami. Improvements and small expansions were made to existing systems, and lines that have been destined for elimination were rehabilitated.

During its development, the transit industry rightly continued its reliance on the railroad industry and its suppliers for the availability and improvement of track components. With thousands of miles of operating tracks, leading railroads have been the major innovators in track improvements and the major market for the manufacturers of the track components and other materials used by the transit industry.

Long years of careful investigative efforts by railroad and transit engineers overcame the more hazardous and costly problems once found in transit track. These efforts also provided a body of knowledge and a quality of track materials sufficient to build and keep transit track in very good condition.

In recent years, with rare exception, transit track has far exceeded Federal standards¹ for its speed class. In relation to the weight and speed of traffic, transit rail is heavier and the track structure is stronger than railroad track. The strength, safety and durability of present day transit track have resulted from many years of engineering efforts to improve railroad and transit track. A body of expert knowledge was developed among transit engineers, and the best practices of railroads were used in transit track. Although it carries lighter loads than railroad track, transit track has high safety requirements and high traffic frequency. The latter makes repetitive track adjustment and minor repairs much more costly than they usually are on railroad tracks.

¹Standards, p. 3.

In recent years, railroad requirements and transit requirements for track structures have been diverging more and more. This has resulted from the increasing weight and tonnage of modern railroad cars traveling over thousands of miles of ballasted track, while transit systems use relatively few miles of ballasted track on soil embankments and continue to load it lightly. A strong and continuing effort in recent railroad engineering has been to find ways to reduce damage to overloaded track structures and to repair and strengthen ballasted track at minimum cost. The information produced has been of only minor interest since most of it is not applicable to the problems of the transit industry.

2.2 CURRENT STATUS

At present, over 1340 miles of rapid transit track are in operation. On this revenue track over 9800 cars provide more than 1.7 million passenger rides per year in 10 U.S. cities. In addition, 160 miles of revenue track are in design or under construction, and 140 miles of track are planned which will bring rapid transit to a total of 12 cities. Numerous rehabilitation projects are underway or planned, and strenuous efforts are being made to upgrade track maintenance in order to meet increasing demands. Fuel shortages, especially gasoline, have resulted in increasing emphasis on rapid transit as a fuel-efficient transportation alternative to automobiles. The rehabilitation of city housing along with the population movement back towards the convenient inner cities indicate future increases in the demand for transit. This is especially true wherever large corridors of urban activity exist, coupled with interest in a strong central business district. In addition the large increase in air travel has generated a singular requirement for quick and easy access to airports.

Additions, expansions and improvements to rapid transit systems are hampered greatly by high costs that continue to rise

rapidly. In addition, ride quality and noise on some existing transit lines may affect passenger satisfaction enough to keep the projected demand for transit below levels that would support expansion and improvement.

These conditions dictate the need for changes in transit track design, construction and maintenance to help offset rising costs, improve ride quality and reduce noise. Such changes are not easy to make or even to envision. The present high levels of safety and strength of transit track are a result of the expert knowledge of track gained over many years of transit engineering practice, the use of the best methods of railroads to build and maintain transit track, and the numerous improvements that have been added year after year.

Many railroad practices are not applicable to transit track today because the conditions under which the tracks are now used differ so widely. Railroad tracks are built to resist high speeds and very heavy wheel loads. The long lengths of railroad tracks and wide clearances permit the use of large construction equipment for building embankments and drains, handling bundles of ties, fastening rails and lining track. The same conditions affect inspection and maintenance, and emphasis is placed on large, high-speed machines for inspection and maintenance² as well as construction. These large and expensive machines would not be as cost-effective on transit systems as on railroads, even if they could be modified to fit transit clearances, because of the relatively few miles of track to be built and maintained at any particular location.

The situation is similar in recent research on railroad track. Some of the information on rail wear⁶ may be translatable to

²AREA, p. 5.

⁶Steel, R.J. and Kucera, W.J., "Rail Metallurgy Tests at Fast-Review and Update," Railway Track and Structures, May 1978.

transit track conditions, but most of the information produced by railroad research is not applicable to transit track. With the exception of CWR, it appears that it would not be advantageous to incorporate the improvements developed for the U.S. railroad tracks over the past ten years into transit track. In fact, the results would be very costly and probably no better for transit traffic than the tracks built previously.

Developments among European railroads and transit systems are of interest to U.S. transit systems because wheel loads have remained in a comparable range. European efforts have focused on many developments such as ballast compaction that could be applied to transit track as discussed in Section 7. Some of the results would not be advantageous, however, because they were developed for a situation that existed in Europe until quite recently in which labor costs were much lower than material and equipment costs. As a result some of the track components are delicate and complicated, and some of the maintenance methods are labor intensive.

2.3 RESEARCH NEEDS

The need to direct special efforts to track problems and opportunities of particular significance to transit systems has been recognized in a series of research studies under the UMTA Track Research Program. The Transit Track Systems Study was initiated as one of these studies.

Other projects to meet needs identified under the UMTA Program include: a study of design tools and criteria for ballasted track and slab track at grade;⁷ a study of requirements for

⁷Prause, R.H., Meacham, H.C., Harrison, H.D., Johns, T.G., Glaeser, W.A., and Waddell, J., "Assessment of Design Tools and Criteria for Urban Track Structures; Volume I, At-Grade Tie-Ballast Track and Volume II, At-Grade Slab Track," Battelle, Report Nos. UMTA-MA-06-0025-74-3 and -74-4, April and August, 1974.

evaluating rail joints and fasteners;⁸ development of a plan to test and evaluate methods to control urban rail system noise;⁹ investigation of concrete tie designs, including the preparation of preliminary specifications, laboratory tests and evaluations,¹⁰ and arrangements for field tests; an investigation now underway to determine the suitability of slab track at grade for U.S. transit requirements; a study also underway to find the most effective designs, installation procedures and maintenance methods for the restraining rails used in transit track; and surveys of transit properties by APTA to obtain opinions on research needs.

2.4 PROJECT SCOPE

The Transit Track Systems Study was initiated to help increase the performance, reliability and safety of urban rapid transit track systems by identifying and assessing track-related problems, and identifying potential solutions and research tasks which could alleviate the problems. The objectives were to evaluate and assess U.S. rapid transit track conditions (including design, construction and maintenance problems and practices) and to define research requirements in order of priority, based on the evaluation and on life-cycle cost analyses. The results are expected to help ensure that continuing track research provides maximum benefits to the transit industry.

⁸Prause, R.H., and Harrison, H.D., "Data Analysis and Instrumentation Requirements for Evaluating Rail Joints and Rail Fasteners in Urban Track," Battelle Report No. UMTA-MA-06-0025-75-8, February, 1975.

⁹Saurenman, H.J., and Holowaty, M.C., "In-Service Performance and Costs of Methods to Control Urban Rail System Noise, Test and Evaluation Plan," Wilson, Ihrig & Associates, Inc., and DeLeuw, Cather and Co., Report No. UMTA-MA-06-0025-77-10, April, 1977.

¹⁰Hanna, A.N., "Measurement Program for Evaluation of Concrete Ties and Fastenings in Transit Track," "Preliminary Specifications for..." and "Laboratory Evaluation of..." Portland Cement Association Reports Nos. UMTA-MA-06-0100-79-2, 3 and 8, March 1979.

The work effort was planned to cover a great many items in track design, construction, maintenance and inspection, in order to identify and define the essential products. These essential products are definitions of favorable research tasks in a value-based order of priority, and descriptions of state-of-the-art techniques that have potential for reducing costs and/or improving the quality of track.

3. TRACK INVENTORY

3.1 TRACK STRUCTURE TYPES

There are many different types of transit track structures in use in the U.S. Some types that were once popular are no longer built because they are noisy or unsightly, ore more difficult to maintain than other types. Each major type of track structure has many minor variations. Fig. 1 shows a subway track with the rails supported on wood blocks embedded in a concrete slab. The center drain is unimpeded except by the long ties that hold the rails to gage and support the contact rail, at intervals of approximately ten feet. In later variations of concrete slab track, the long ties were not used since the blocks, firmly embedded and bolted to the concrete, were sufficient to hold gage and support the contact rail. Rails in subways may also be supported by elastic fasteners bolted directly to the concrete as shown for an elevated track in Fig. 5.

The ballasted track shown in Fig. 2 is no longer installed in subways except for short lengths of special trackwork to match existing track. The wires shown in the picture are heavy copper "bonds" fastened tightly to the rails to make sure that electrical signals and electrical power from the cars have a good path to the power substation. Ballasted track is still being installed on the surface at ground level and on embankments, both with concrete ties as shown in Fig. 3, and with wood ties.

Elevated track with an open deck structure, such as that shown in Fig. 4, is no longer favored because of high noise levels. Elevated concrete slab track, as shown in Fig. 5, and ballasted track, as shown in Fig. 6, have lower noise levels. The concrete slab track is generally preferred where elevated structures are necessary.

Fig. 1

Subway Track With Wood
Blocks Embedded In Concrete

Large ties are installed every ten feet to hold track gage and also to support the contact rail which is off to the right of the picture. The rails are fastened to the blocks with screws and held longitudinally by rail anchors.



Fig. 2

Subway Track With Wood
Ties In Ballast

Patterned after ballasted surface track, this track is easy to adjust but difficult to clean and drain when the ballast clogs with oily dirt.



Fig. 3

Surface Track With Concrete
Ties in Ballast

The rails are seated on elastic pads and fastened with spring clips bolted to threaded holders in the ties. The spring clips restrain the rails both longitudinally and vertically.



Fig. 4

Elevated Track With Wood
Ties On Steel Structure

The rails are fastened with tie plates and cut spikes, plus a few spring clips for longitudinal rail restraint.



Fig. 5

Elevated Concrete Slab
Track

The rails are held by fasteners that include elastic pads to provide track resiliency.



Fig. 6

Elevated Track With Wood
Ties In Ballast

The track on the left has been rebuilt with spring clips, while the track on the right has track screws holding the rails.



The angle irons shown in Fig. 5 installed between the running rails serve as guardrails that cost less to buy and install than T-rail does. If a car were to derail, the guardrails would hold its wheels to a path on the concrete slab close to running rail and thus prevent the cars from hitting obstructions or running off the elevated structure.

The ballast-on-slab elevated track shown in Fig. 6 is quieter and easier to adjust than slab track, but it is more expensive to build and may cost more to maintain except in cases where the support structure moves or settles, consequently requiring large track adjustments.

On short bridges, the track support structure is either concrete slab or ballast-on-concrete slab to match the adjacent embankments; while on long bridges, the track is usually supported by an open deck as shown in Fig. 4 in order to minimize weight.

3.2 INVENTORY DATA

Track inventory data were collected under major types of structures, and minor variations of these were lumped together. Thus the concrete slab track, listed under subway or tunnel and elevated locations in Table 1, includes slab track with rails supported on wood ties, wood block "ties," or direct fixation fasteners. The wood ties or wood blocks may be fastened on the concrete or embedded in it.

The track inventory data were provided by the transit properties on an inventory form developed for the project and approved by the Transit Track Systems Study Liaison Board.* The form was developed to obtain data that could be readily summarized

*An advisory board consisting of representatives of transit properties and members of the APTA staff.

to nationwide totals that would be useful in overall estimates of trends and replacement requirements. Track data are summarized in Table 1. Earlier track inventories with data collected by APTA¹¹ and consultants¹² were very useful, as was a preliminary design study made by the Metropolitan Dade County Transit Authority.¹³ A large amount of information received on track features, design limits and maintenance practices varied so much that it could not be summarized to meaningful totals. However some of the items included had ranges of application that are of interest. These items are listed in Table 2.

Data on transit car sizes, weights and other characteristics are provided in an APTA report¹⁴ for cars built between 1945 and 1977. The axle loads range from a minimum of approximately 10,000 lbs. for an empty 6001 series car of the Chicago Transit Authority (CTA) to a maximum of approximately 30,000 lbs. for an R-16 series car of the New York City Transit Authority (NYCTA) with a crush load of 220 passengers. The heaviest car built before 1945 and still in use is on the Broad Street Subway of the Southeastern Pennsylvania Transit Authority (SEPTA). It weighs approximately 142,000 lbs. when carrying a crush load of 212 passengers, and the axle load on the truck equipped with traction motors is approximately 40,000 lbs. The wide range of axle loads is not very significant in the design of the track itself, since the track components normally available

¹¹ "Track and Right-of-Way Characteristics for Ballasted Track-Rolling Stock Characteristics - Operating Conditions," Section V of "Technical Reference Report No. 1," APTA, Oct. 1975.

¹² Dunn, R.H., et. al., "Trackwork Study Volume 1 Trackwork Practices of North American Rapid Transit Systems," DeLeuw, Cather and Co., Report No. WMATA-DCCO-TWS-1, Nov. 1967.

¹³ "Basis for Design of Track, Metropolitan Dade County, Stage I Rapid Transit System," Draft, Aug. 1978.

¹⁴ "Roster of North American Rapid Transit Cars, 1945-1976," American Public Transit Association Report No. UMTA-DC-06-0121-77-1, Jan. 1977.

TABLE 1. TRANSIT TRACK SUMMARY

a. <u>Track Location and Structure</u>	<u>Miles of Single Track</u>		
	<u>In Operation</u>	<u>In Design or Construction</u>	<u>Planned</u>
Subway or Tunnel			
Concrete Slab	378.9	68.7	11.2
Ballasted	257.3	0.6	--
Surface, Ballasted			
Concrete Ties	95.2	18.6	40.1
Wood Ties	186.2	41.2	54.0
Elevated			
Embankment, Conc. Ties	--	1.7	--
Embankment, Wood Ties	69.7	--	--
Open Structure	257.6	--	--
Concrete Slab	56.2	56.5	32.8
Ballast on Concrete	27.0	--	--
Bridge	12.7	0.4	--
TOTAL (rounded)	1341	187	138
b. <u>Rail by Weight and Joint Type</u>			
85-1b. CWR	36.0	14.0	--
100-1b. CWR	123.6	2.1	--
112-1b. CWR	5.4	--	--
115-1b. CWR	104.4	174.4	138.1
119-1b. CWR	136.1	3.2	--
132-1b. CWR	22.3	--	--
85-1b. BJR	13.2	--	--
90-1b. BJR	71.6	--	--
100-1b. BJR	791.3	--	--
115-1b. BJR	12.8	0.3	--
119-1b. BJR	8.0	--	--
130-1b. BJR	2.0	--	--
c. <u>Components</u>	<u>Number in Track</u>		
Wood Ties in Ballast	2,000,000	105,000	2,500
Wood Ties on Open Structure	890,000	--	--
Wood in Conc. Slab/Invert	860,000	90,000	--
Wood on Conc. Slab/Invert	20,000	300	--
Concrete Ties in Ballast*	205,000	65,000	--
Direct Fixation Fasteners			
Pandrol	--	75,000	--
Hixen	145,000	280,000	180,000
Elastic	--	35,000	10,000
Toronto	11,000	--	--
Landis	200,000	--	--

c. <u>Components</u> (cont'd)	<u>Number in Track</u>		
	<u>In Operation</u>	<u>In Design or Construction</u>	<u>Planned</u>
Tie Plates 6"x10" to 8"x14"& 7"x16"	7,540,000	390,000	5,000
Joint Bars			
36"	300,000	2,500	--
24"	270,000	--	--
Insulated Joints			
24"	1,300	300	--
36"	20,000	1,500	300
48"	30	--	--

d. <u>Turnouts</u>					e. <u>Crossovers</u>				
<u>Size</u>	<u>In Operation</u>		<u>In Design or Construction</u>		<u>Size</u>	<u>In Operation</u>		<u>Construction</u>	
	<u>Line</u>	<u>Yard</u>	<u>Line</u>	<u>Yard</u>		<u>Line</u>	<u>Yard</u>	<u>Line</u>	<u>Yard</u>
3.5	6	45	--	--	4S	23	22	--	--
4	17	329	--	--	5S	32	12	--	--
4.5	--	2	--	--	5D	19	8	--	--
5	34	463	--	1	6S	113	36	--	--
6	126	144	--	135	6D	63	17	--	3
7	40	14	--	--	7S	30	--	--	--
8	89	195	33	66	7D	6	--	--	--
9	7	2	--	--	8S	93	9	14	6
10	166	5	5	2	8D	41	1	5	--
11	5	1	--	--	9S	24	--	--	--
12	18	2	--	--	10S	25	--	22	--
15	21	--	2	--	10D	21	--	8	--
20	10	--	2	--	11S	4	--	--	--
SPE	47	284	--	--	12S	4	--	--	--
					12D	1	--	--	--
					15S	4	--	--	--
					15D	1	--	--	--
					20D	1	--	--	--
					SPE.S	89	17	--	--
					SPE.D	63	20	--	--

Notes: Paragraphs a, b and c of the table do not include yard track.

All ballasted subway track has wood ties.

All elevated tracks with open decks or ballast have wood ties.

CWR - Continuous, welded rail

BJR - Bolted-joint rail

SPE - Special, Unclassifiable

S - Single

D - Double

*Rail is fastened to concrete ties and some wood ties with bolted spring clips. The current trend is towards use of drive-type spring clips that require less maintenance.

TABLE 2. TRANSIT TRACK DATA

<u>Item</u>	<u>Range</u>
Grade, maximum	3 to 5 percent
Grade, maximum in station	0.35 to 0.50 percent
Curve, Horizontal, minimum	115 to 1000-foot radius
Curve, Horizontal, minimum in station	3000-foot radius
Curve, Vertical, minimum length	100 to 800 feet
Superelevation, Balanced, maximum	4.5 inches
Superelevation, Unbalanced, maximum	1.75 inches
Lubrication in curves	None to all curves to 1500-foot radius
Rail weight per yard*	85 to 132 pounds
Restraining rails	None to all curves to 1500-foot radius
Guardrails	None to all bridges, elevated structures, high embankments and wayside structures
Rail Cant	1 in 40 to 1 in 20
Gage on Tangent	56 1/4 to 66 inches $\pm 1/8$ inch
Gage Widening on curves	1/2 to 1 inch $\pm 1/8$ inch
Wood Tie Spacing, open deck bridges	15 to 18 inches
elevated structures	24 inches
surface	24 to 30 inches
subways and tunnels	22 1/2 to 24 inches
Concrete Tie Spacing	30 inches
Concrete Tie Spacing, two- block ties	30 and 36 inches
Direct Fastener Spacing	26 to 36 inches
Welded Rail Joints	Tangent only to all track
Rail Expansion Joints	On long bridges

Note: *New designs call for 115-lb rail except to match existing rail.

and in use are adequate for the heaviest loads. The axle loads are significant, however, in the design of support structures such as bridges and elevated structures, and the heavier loads increase the rate of rail wear.

3.3 RELATED INFORMATION

Three of the twelve rapid transit systems in the U.S. operate light rail systems as well as heavy rail systems. These are the Greater Cleveland Rapid Transit Authority (CRTA), the Massachusetts Bay Transit Authority (MBTA) and the Southeastern Pennsylvania Transit Authority (SEPTA). All three properties provided data on their light rail systems, but since they constitute only a small part of the total light rail and commuter rail in operation in the U.S., the data have not been included in this report.

Miscellaneous track and track-related information was obtained from transit properties, architectural and engineering firms, other consultants, and available reports. This information was evaluated with track inventory data as to its suitability for a track data base. While the data were adequate for comparative evaluations of current practices, they were found to lack sufficient accuracy and density and to have too much scatter to form an actual data base. Much of the information, other than track inventory, is approximate; it was obtained from the recollections of transit personnel, since accurate records were available in only a few cases. Improvements in this situation can be expected when a project is completed which will produce a uniform chart of accounts plus uniform accounting and planning procedures for the transit properties. Uniform procedures will assist in the identification and recording of relevant track data and will help to determine which track data should be collected and processed by management information systems into information that will assist management decisions.

The quantity of track and other facilities data that will be worth the costs of collecting and processing in a data base is not expected to be large. The data bases found to be effective by industrial organizations generally contain only

very broad facilities data consisting of locations, capacities, overall costs and trends.^{15,16} Details are left in the hands of plant managers, plant engineers and consultants. The emphasis is on simplifying and reducing the data to quantities that top management can use effectively in planning. Major reasons for leaving detailed information on facilities in the hands of the local managers are that they make the most use of it, and they can maintain and update the data at minimum cost. In addition, the large variations in the detailed information caused by local conditions (usage rates, labor and material costs, availability of skills, weather conditions, age of facilities) detract from the significance of the details when they are assembled at a management center.

Similar situations were encountered when the principal investigator worked with other data bases, including one for military facilities in the Pacific areas. These data bases contained large quantities of accurate and detailed information, but the quantity and complexity of the data made processing very costly and prevented managers from making effective use of them. When the collectors of data at the facilities involved realized the data were not being used extensively, the costs and efforts of data collection were gradually reduced, and error crept in rapidly during frequent updates. Restructuring these data bases was tedious. It consisted of evaluating hundreds of items for significance, and simplifying and consolidating the relatively few data that were found to be essential. In the process, great advantage was found in leaving detailed facilities data with local managers and plant engineers, and providing them with uniform guidance on recording and using the data.

¹⁵ Tsichritzis, D.C. and Lochovsky, F.H., Data Base Management Systems, Academic Press, 1977.

¹⁶ Ross, J. E., Modern Management and Information Systems, Reston Publishing Co., Prentice-Hall, 1976.

4. TRACK CONDITION

4.1 GENERAL

A large number of factors govern the condition of transit track. A track in good condition is safe, has a smooth, comfortable ride quality and does not deteriorate rapidly under traffic.

The many factors that govern track condition range from the weight of rails and the amount of wear they have undergone to the drainage beneath the roadbed. Some items (such as track components) can be counted and measured, but only a few factors can be measured readily with consistent accuracy. These include the position of the rails (track geometry) and the accelerations forced upon cars as they travel over rail deviations. The evaluation of other factors (such as the condition of a tie with rot in it) can be improved by giving them separate consideration and by using check lists. These check lists improve the consistency in the evaluations and reduce the level of subjectivity inherent in all inspections.

The transit tracks that have been observed generally exceed Federal standards² for their speed classes. In relation to the weight and speed of traffic imposed upon it, the transit rail is heavier, and the track structure is stronger than railroad track. Generally it is maintained in very good condition for its traffic except for short wavelength rail deviations that contribute to noise and poor ride quality.

A reduced level of maintenance has been noted on lengths of track that are soon to be rebuilt or removed, but safety has not been reduced, as operating speeds are commensurate with track condition. Safety can be maintained when track conditions

¹Standards, p. 3.

deteriorate by reducing the speed of traffic. This is indicated in the Safety Guidelines¹⁷ published by APTA where maximum allowable speeds are related to measurable track conditions.

Track condition becomes less critical as operating speed is reduced, because the lateral and vertical accelerations of cars that are caused by track deviations vary approximately with the square of the speed. At very low speed, a skillful motorman can ease cars over a serious track defect that would derail the cars at high speeds. Accordingly, traffic may be operated safely over tracks at many different levels of condition, from excellent to very poor, by adjusting the operating speed to suit the track condition.

4.2 TRACK SURVEYS

In the course of the work under the track study, 52 sample lengths of track (nominal 1000-foot lengths) were surveyed and examined in detail. Automatic equipment was not available for collecting and processing either track geometry or ride quality data. Accordingly a "Roll Ordinator" was used to measure alignment and profile deviations as shown in Figs. 7 and 8, and a "Track Chek" was used to measure crosslevel and gage as shown in Fig. 9. These inspection devices are normally used to identify exceptions to allowable tolerances for corrective work by track maintenance crews. The devices simplify the measurement processes when compared to the use of handtools such as stringline, tracklevel and gage, although they do not have the speed of automatic equipment or provide data in a form suitable for computer processing. In order to use the collected data to quantify track condition, a special methodology was developed. This methodology is not intended for general use, since automatic data processing techniques are more suitable when track survey data is to be used in planning and maintenance control.

¹⁷Moving People Safely, Safety Guideline for Urban Rapid Transit Systems, 3 ed., American Public Transit Association, Nov 1977.

Fig. 7

Measuring Rail Alignment
And Profile

Alignment and profile are determined from midchord offsets measured from the rail to a straight line. The line is actually a taut wire moved along the rail with the device shown.



Fig. 8

Reading Mid-Chord Offsets
From A 20-Foot Chord

Flashlights were used in subways and at night on surface track when measuring rail alignment and profile.



Fig. 9

Measuring Track Gage and
Crosslevel

Gage is shown on the small dial, being the distance between the flanges of the measuring wheels. Crosslevel is shown on the large dial, and is taken from the angle of a damped pendulum.



The sample lengths of track were surveyed by measuring rail irregularities in alignment and profile as offsets from a 20-foot chord at 10-foot intervals and at intermediate points wherever abrupt deviations were found. A 20-foot chord was selected, because it is a convenient length to use on sharp curves, and also because it gives good indications of the track irregularities in the wavelengths that seriously affect the ride quality of transit cars. The 20-foot chord was moved along the track on a "Roll Ordinator," which also carried a vertical and horizontal scale graduated in sixteenths of an inch, to show offsets from the chord as indicated in Fig. 9. The gage and crosslevel measurements at the same points along the track were read from the dials of the "Track Check" which was rolled along the track as shown in Fig. 8. These measurements were checked with a combination track level-gage at the beginning and end of each survey zone to make sure the equipment was adjusted properly.

Unusual conditions such as large gaps between rail ends at joints, misalignment of rail ends, deep corrugations in rails, worn frog points, and wide flangeways were measured with hand tools. These included straight edge, rule, surface depth gage, taper gage, probe and tools for cleaning track components.

Many miles of track were observed from trains to gain an appreciation of the general quality of the ride as well as the condition of the track, and to observe any unusual conditions. Some zones with interesting features (in addition to those surveyed) were inspected on foot in order to relate them to the zones that had been surveyed for ride quality and general conditions.

Conditions observed in ballasted track are illustrated in Figs. 10 and 11, while Fig. 12 shows elevated slab track. The ballasted surface track shown in Fig. 10, with continuous welded rails (CRW) in excellent condition, is on a high embankment at the approach end of a station. The short guardrail shown

Fig. 10
Ballasted Track In
Excellent Condition

The rails are fastened to the plates with spring clips to restrain the CWR longitudinally and vertically. The tie plates are fastened to the wood ties with lock spikes.



Fig. 11
Ballasted Track In Poor
Condition

This rough track at the transition of an embankment and a station structure is scheduled to be rebuilt.

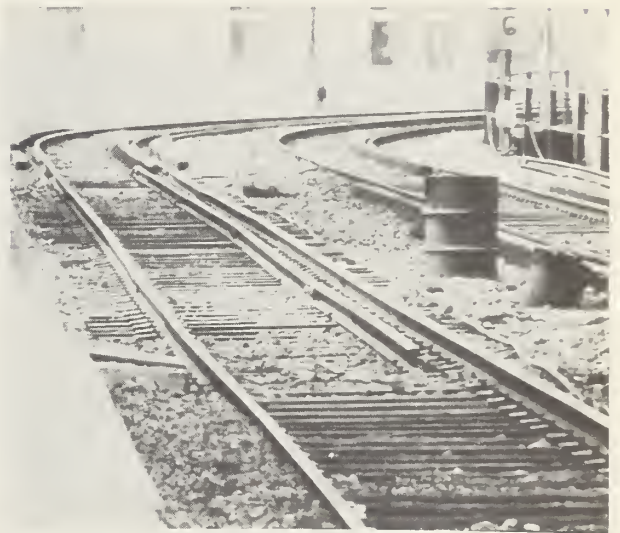


Fig. 12
Elevated Concrete Slab
Track, Very Good Condition

The wood blocks and large ties embedded in concrete are similar to the subway track structure shown in Fig. 1.



between the running rails to the left of the track center line has the function of preventing cars from hitting the end of the platform if a derailment should occur. In this case, the guard-rail would hold the derailed wheels to a path between it and the running rail. If a car were to derail towards the left side of the track shown in Fig. 10, the long guardrail to the right of the track center would prevent the car from hitting the poles or other obstructions to the left and from running off the embankment.

Fig. 11 shows a track in poor condition at the end of a station where changes in the stiffness of the supporting structure appear to have contributed to impacts and deterioration of the track. This structure is scheduled to be rebuilt in the near future. Fig. 12 shows an elevated concrete slab track in very good condition, while Fig. 13 shows a similar, older track that has deteriorated to a poor condition and is scheduled to be rebuilt. The exposure of wood ties on elevated tracks leads them to split and rot at a slightly faster rate than ties in ballasted surface track. The badly deteriorated ties in the elevated, ballasted track shown in Fig. 14 were said to be over 35 years old. New ties and rails were installed shortly after the picture was taken.

Fig. 15 shows an elevated CWR slab track in excellent condition with direct fixation fasteners supporting the rails. The fasteners are fitted with elastic pads to give the track resiliency.

4.3 RATING TRACK CONDITION

4.3.1 CONDITION INDICATORS

As noted in Section 4.1, only a few of the factors that affect track condition can be measured consistently. Attempts to systematize the evaluation of all the important factors (measurable or not) showed that they can be grouped under three major qualities of the track:

Fig. 13

Elevated Concrete Slab
Track, Poor Condition

The deteriorated wood blocks and ties and the worn rail are scheduled for early replacement.

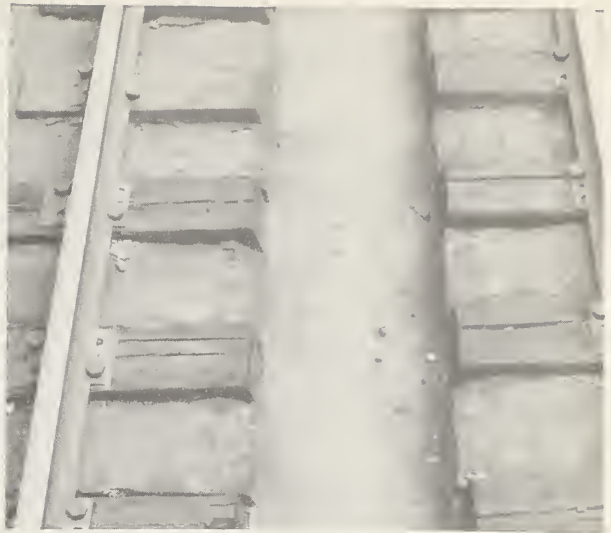


Fig. 14

Elevated Ballasted Track
In Poor Condition

The deteriorated wood ties and worn rail are soon to be replaced. This picture shows a restraining rail bolted to the running rail, a guard rail to the left and a contact (power) rail with cover to the right.



Fig. 15

Elevated Slab Track In
Excellent Condition

The rails in this new CWR track are held with direct fixation fasteners bolted to threaded holders in the concrete slab. A deck drain is shown between the rails.



- Smoothness which governs the safety and ride quality of the track.
- Durability which ensures continuing safety and ride quality in the immediate future.
- Maintainability which permits long-term continuance of track safety and good ride quality.

Smoothness and durability affect one another. A durable track stays smooth longer under traffic, while a smooth track is more durable than one of equal strength that is subject to jolts and pounding impacts because of its roughness under traffic. In addition, smoothness itself is an indicator of durability in a track that is still relatively smooth after carrying traffic for several years. Accordingly, smoothness is considered the most important indicator of track condition, and it was assigned a maximum of 60 points out of a possible 100 points (for a track in near perfect condition).

Durability is the quality of strength and toughness that gives a track its resistance to deterioration under traffic and environmental factors. The track should carry the loads imposed upon it by traffic without any components being overstressed at any point, especially at their connections and interfaces with other components. Durability is a very important track quality and was assigned a maximum of 30 points.

Maintainability (ease of maintenance) is important to the continuing smoothness and durability of the track because many components cannot be made to last the life of a transit track, and others require adjustment to compensate for gradual wear under traffic. Unless short-lived components can be adjusted and/or replaced easily and economically, the work tends to be deferred, and the track deteriorates to a rougher, weaker condition. Accordingly maintainability is assigned a maximum of 10 points out of a possible 100 points in rating track conditions.

4.3.2 RATING PROCEDURES

4.3.2.1 Smoothness

Track geometry parameters were measured in sixteenths of an inch for the convenient use of available tools and instruments. Deviations were found for alignment, profile and crosslevel by taking groups of three consecutive measurements and subtracting the center measurement from the mean of the two end measurements. The differences found for alignment and profile were irregularities where the rail deviated from a smooth space curve. The crosslevel deviations indicated twist or warp which degrades ride quality and increases derailment tendencies. Gage deviations were found by comparing the design gage of the track to the measured gage.

The measured deviations were summed and weighted at several levels so as to distinguish a wide range of smoothness levels among tracks. The maximum smoothness rating of 60 would be given to a track with no rail deviations from a smooth curve that exceeds $3/16$ of an inch in 20 feet for alignment, profile and crosslevel; no gage more than $5/16$ of an inch wide or less than $3/16$ inch narrow; and no anomalies (roughness) at joints or in special track work. Points were deducted from the maximum rating for measured deviations that exceed the limits stated above. Points were also deducted for roughness found at bolted joints and other irregularities.

The procedures used for rating smoothness are complex, and the work required was tedious. As indicated previously, automatic systems to collect and process smoothness data would be cost effective if repetitive measurements were needed as in the planning and monitoring track maintenance. In any case, close observations and manual measurements are necessary to rate the durability and maintainability of a track.

4.3.2.2. Durability

Track components were inspected and their conditions were estimated or measured as appropriate. Some factors such as depth of ballast, spacing of ties or fasteners and weights of rails can be measured. Others, such as rail corrosion, the extent of ballast fouling and the deterioration of elastic pads in direct-fixation fasteners, must be estimated. Still others, such as weakening of subbase materials, must be observed indirectly through their effects (such as sagging profile or mud pumping) unless expensive tests are made. The movement of rails under traffic loads is a very good indicator of track durability, but special equipment would be required to make more than a few measurements of rail movement.

The supporting structure, or subbase under ballast or concrete slab, should support the track structure and all traffic loads without distress. A subbase should also resist mud pumping from below the ballast, resist working at joints and cracking in track slabs, prevent sags in track profile, and resist degradation of geometry in ballasted track.

Ballast, if used to support the track, should fill the cribs and shoulders to the tops of ties except at switches. The ballast shoulders should extend level at least 6 inches beyond the ends of the ties, unless lateral stability is provided by bracing the track or anchoring it. The ballast should be clean and should meet gradation and quality specifications; it should support ties firmly and hold the track in alignment.

Ties should be in condition to support the rails firmly, hold them to specified gage, and transfer vertical and horizontal loads from the rails to the ballast, concrete slab or other track support structure. They should be at specified intervals and should not be skewed or loose to the extent that it impairs

their function. Ties in special track work should be long enough to hold the entire assemblies together firmly when traffic passes over them.

Rail fastenings (including cut spikes, screw spikes, lock spikes, bolts, spring clips, tie plates and pads) should be installed in the numbers and locations specified. They should be in condition to perform their function of holding the rail in position and distributing the load so as to protect the tie. Spikes need not be driven down tightly on the flange of the rail, as the rail tends to float above the ties when affected by the uplift force of rolling wheel loads, and the inward cant of the rail resists wheel forces that tend to overturn it.

Direct fixation fasteners should be in condition to perform the same functions as listed above for ties. In particular, bolts should be lubricated and tight, base plates should be in contact with the support structure, and elastic pads should be held in specified positions.

Rails should be the specified size and type and should be within specified wear limits. They should be free of visible cracks and large spalls or chipped areas on the gage side of the head. They should not be weakened excessively by corrosion.

Rail ends should be smooth and square and should be within the limits specified for mismatch, rail end batter and gaps at joints.

Bolted joints should have the specified size and type angle bars and bolts. Nuts should be torqued to specified bolt tension, and threads and fishing surfaces should be lubricated. Joint bars should be bent to match the rail on short radius curves. Joint bars should not permit vertical movement of either rail end.

Special track work should not be worn beyond specified limits. It should be fastened firmly, so that components cannot deflect or move horizontally beyond specified limits, and so that sub-assemblies cannot move relative to each other. Switch points should close firmly against stock rails, and frog points should be protected by guards in specified positions.

While drainage is not itself a track component, it has large and continuing effects on track condition. Water generally weakens all subbase material except durable rock. Water is also the primary cause of the most serious problems found on track embankments. Accordingly, good drainage is essential to the safety and efficiency of track that is installed on ballast or slabs on embankments. Good drainage is also important for retarding the clogging of ballasted track in tunnels and subways, and for reducing the rate of corrosion of rail and fastenings.

Drainage should keep track in subways and tunnels dry at all times. It should drain all water from outdoor tracks shortly after rain has stopped or snow has melted.

For consistency in evaluating durability, major factors are identified and weighted as shown in Table 3.

4.3.2.3 Maintainability

A few maintainability factors can be counted or measured. These include clearances, track availability time, fasteners that can be adjusted to compensate for movement of track supports, braces that can be adjusted to compensate for wear of restraining rails, and an adequate supply of spares.

Maintenance control was considered the most important factor. It includes making the track available for maintenance with minimum traffic interruptions as well as planning, scheduling and other management functions that facilitate effective and economical track maintenance.

TABLE 3. TRACK DURABILITY CHECK LIST

	<u>Maximum Points</u>
<u>Track Support Structure</u> - consider the support structure as one of four basic arrangements with maximum allowances for components as follows:	12
Conc. slab/invert: slab and subbase-10; drainage-2; or wood ties in concrete-8 drainage-3.	
Open deck: ties and connectors-4; steel supports-7.	
Ballasted deck: ties-3; ballast-3; deck-3; drainage-2.	
Ballasted embankment: ties-3; ballast-3; drainage 3; subbase-1.	
<u>Fasteners</u> - consider design, spacing, tightness of bolts, lubrication, corrosion and any damage.	4
<u>Rail</u> - consider weight, wear, corrugations, damage-4; rail ends at joints and conditions at welds-2.	6
<u>Curvature</u> - consider radii, lengths and number of curves; restraining rail and fastenings; and lubrication.	3
<u>Special Trackwork</u> - consider quantities, sizes, types, wear, play at points and heels and between components, guardrails and other features.	3
<u>Exposure</u> - consider cover, prevailing temperatures, rainfall, humidity, freeze-thaw cycles and exposure to salt water and deicing salts.	2
	<hr/> 30

Accessibility is also an important factor of maintainability. For example, a surface track adjacent to an access road is much easier to maintain than a single track in a small tunnel. Clearances are important in permitting the use of large capacity track maintenance equipment. The types of track components used are significant not only because some are easier to adjust and replace than others, but also because components commonly used

by railroads are more likely to be available than special components. Shelter is also significant, as repair is easier in bad weather, if a track is under an overpass or in a subway.

For consistency in evaluating maintainability, major factors are identified and weighted as shown in Table 4.

TABLE 4. TRACK MAINTAINABILITY CHECK LIST

	<u>Maximum Points</u>
<u>Maintenance Control</u> - consider all controllable factors that affect maintenance quality and productivity. The optimum is positive control of track availability, inspection, planning, scheduling, training, supervision, methods, supplies, advanced equipment and tools for maintenance efficiency.	4
<u>Accessibility</u> - consider all local conditions that affect access to the track. The optimum is a track on the surface or low structure that can be serviced from adjacent roads and tracks.	1.5
<u>Clearances</u> - consider all local factors that limit the use of maintenance equipment. The optimum is a track that can use railroad type maintenance equipment.	1.5
<u>Rail Adjustability</u> - consider all work that must be done to adjust alignment or profile. The optimum is a track with bolted joints on ballast. Adjustable fastener assemblies may be as convenient as ties on ballast, but CWR is considerably more difficult to replace than rail with bolted joints.	1.5
<u>Components</u> - consider the spares on hand and the ease with which replacements can be obtained. The optimum is a track with standard components that are readily available in the area.	1
<u>Shelter</u> - consider working conditions during winter storms. The optimum is a track under cover, so that work can continue without trouble in very bad weather.	0.5
	<hr/> 10.0

4.3.2.4 Track Rating Scale

Following the procedure described previously, ratings were obtained for all track zones surveyed under the contract. They ranged from 95 to 62 on the following scale:

97-100 - Perfect	67-72 - Fair
91-96 - Excellent	61-66 - Poor to Fair
85-90 - Very Good	55-60 - Poor
79-84 - Good	45-54 - Very Poor
73-78 - Fairly Good	Below 45- Unsatisfactory

4.3.3 EVALUATION OF OVERALL TRACK CONDITIONS

The track survey zones were not random samples, since track in many areas could not be surveyed because of traffic conditions, but the survey zones were representative of all the track and included a wide variety of track conditions. The evaluations of the transit engineers were obtained for the revenue track in each system, including the survey zones. Their evaluations were normalized by comparing those which included survey zones to the ENSCO evaluations for the same zones and then applying appropriate factors to all the track in the system. The approximate effect was to apply a uniform bias to all track evaluations, so that the results were comparable for all the transit properties.

The results of the evaluations are given in Table 5. The condition ratings range from 95 (excellent) to 53 (very poor). The track rated at 53 is on a structure that is scheduled to be demolished in the near future. In most cases, track rated below 70 (fair condition) is expected to be rebuilt within the next two years. Some of this track is in poor condition because it was permitted to deteriorate during periods when demolition of the track structures was planned; and these plans were revised later when the need for transit expanded. No track is listed in the category "High Embankment, Concrete Ties in Ballast" as the short lengths of this type of track were not reported separately from surface track with concrete ties.

TABLE 5. TRANSIT TRACK CONDITION SUMMARY

Track Condition Rating	Types of Track Structures										Subtotal	Cumulative Total		
	Bridge	Elevated Ties in Ballast	Elevated Concrete Slab	Elevated Open Structure	High Embankment Wood Ties in Ballast	High Embankment Concrete Ties in Ballast	Surface Track Wood Ties in Ballast	Surface Track Concrete in Ballast	Subway or Tunnel Ties in Ballast	Subway or Tunnel Slab/Invert				
	Equivalent Single Track Miles													
	95							62.9		72.5			135.4	135.4
	94		1.2	54.0									55.2	190.6
	92	1.0						13.1					14.1	204.7
	90				23.0	23.0		20.0					66.0	270.7
	88	3.0	3.1		18.6	13.4		48.2		19.8			106.1	376.8
	85	1.8			54.3	1.3		12.0		29.8			99.2	476.0
	83				30.4			11.5		2.6			47.2	91.7
80	4.5	2.4		48.8	17.6		25.3		54.6	110.9	264.1	831.8		
78				44.2			21.4		106.2	31.6	203.4	1035.2		
75	2.4		2.2				22.3	19.2	41.0	21.6	108.7	1143.9		
73							9.1		19.6		28.7	1172.6		
70				13.8	2.6		0.5		16.0	29.8	62.7	1235.8		
68		8.0							4.0	3.5	15.5	1250.8		
65		1.5		12.5			0.9		13.3	9.4	37.6	1288.4		
63							13.9			1.1	15.0	1303.4		
60		10.3								1.7	12.0	1315.4		
58				8.5							8.5	1323.9		
55		0.5		0.5	11.8		1.1				13.9	1337.8		
53				3.0							3.0	1340.8		

In order to illustrate the distribution of track by condition level, it was necessary to smooth the very high peaks and voids that are evident in Table 5. This was done by averaging the quantities of track across sets of five condition levels, 97 thru 93, 92 thru 88, and so forth. The averages were plotted in Fig. 16 and smooth curves were drawn between them. Approximate quantities and distribution of track are indicated by the volumes between the curves at the various condition levels.

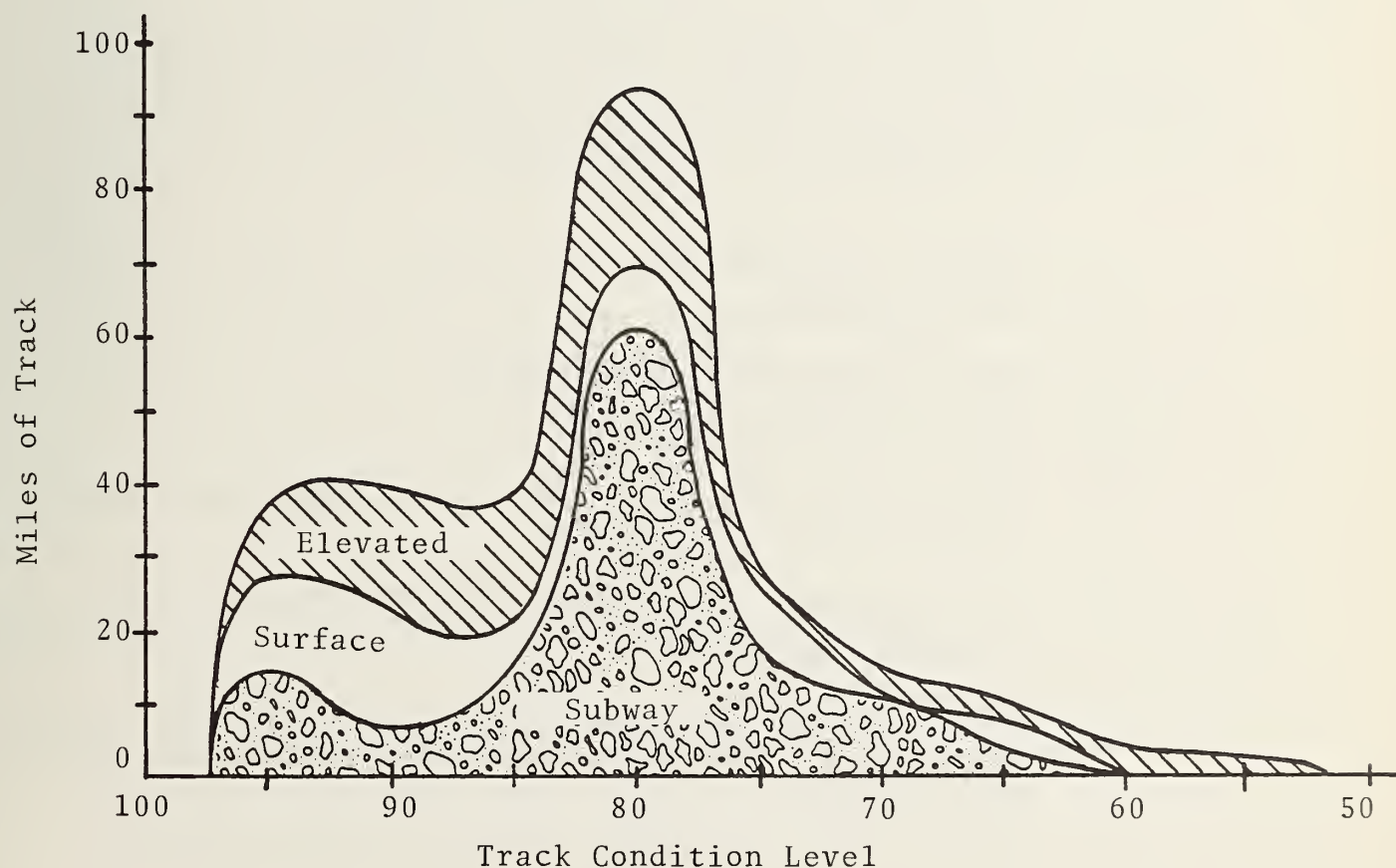


Fig. 16
Track Quantities and Conditions

4.4 EFFECTS OF TRACK CONDITIONS

Transit system reliability, safety and overall performance depend on many factors. These include the condition of the tracks, cars, power, signal, and various subsystems as well as the effectiveness of the people who operate and maintain the system.

When tracks are in excellent condition, train speeds, ride quality and noise levels are determined by the planned track design features and the dynamic characteristics of the cars. As track condition degrades, increasing roughness and accompanying changes in crosslevel and alignment cause vertical, lateral and angular accelerations that:

- Reduce ride quality.
- Increase noise.
- Increase the rate of rail wear.
- Require speed reductions.
- Increase the frequency and costs of emergency track repair and traffic delays.
- Accelerate the development of track defects (such as damaged switch points) that may cause or contribute to derailments.
- Contribute to excessive wear of wheel flanges, treads, and bearings, and cause vibrations that loosen minor parts of cars.
- Lower public acceptance and use of the system.

Track condition affects reliability directly when traffic has to be slowed to pass safely over track that has deteriorated, or when traffic has to be stopped to permit emergency repairs to track. Safety is affected when poor track conditions cause or contribute to derailments. Track conditions that impair reliability or safety clearly affect system performance. Track

conditions also reduce system performance when they increase the costs of operations or maintenance, or annoy users so as to decrease the number of rides sold.

Costs for track maintenance and traffic delays for emergency track repairs are strong indicators of overall system performance, and are clearly related to track condition. Unfortunately most relations between track condition and its effects are not direct or consistent. For example, the sharp curves and short lengths of tangents on some subways require relatively low operating speeds no matter how good the track condition. Raising the condition of such track to a level that would allow a speed of 75 miles per hour on long tangents would improve ride quality but usually would not increase the allowable speed.

While many of the effects of track condition cannot be measured or even determined directly, track condition could be correlated with performance by regression analysis of statistical data. Good records are needed for this, which should be collected continuously over an appreciable length of time while track conditions change.

A methodical procedure to evaluate the effects of track condition at a transit property is outlined in Fig. 17. Under this procedure, a track condition rating would be derived periodically by the evaluation of all the measured and estimated data that determine the major track qualities of smoothness, durability and maintainability. At the same time, the statistical data selected to define the major system performance indicators of reliability, safety and general performance would be assembled and sorted. This data would then be analyzed and weighted (according to local experience and judgment) to produce a System Performance Rating.

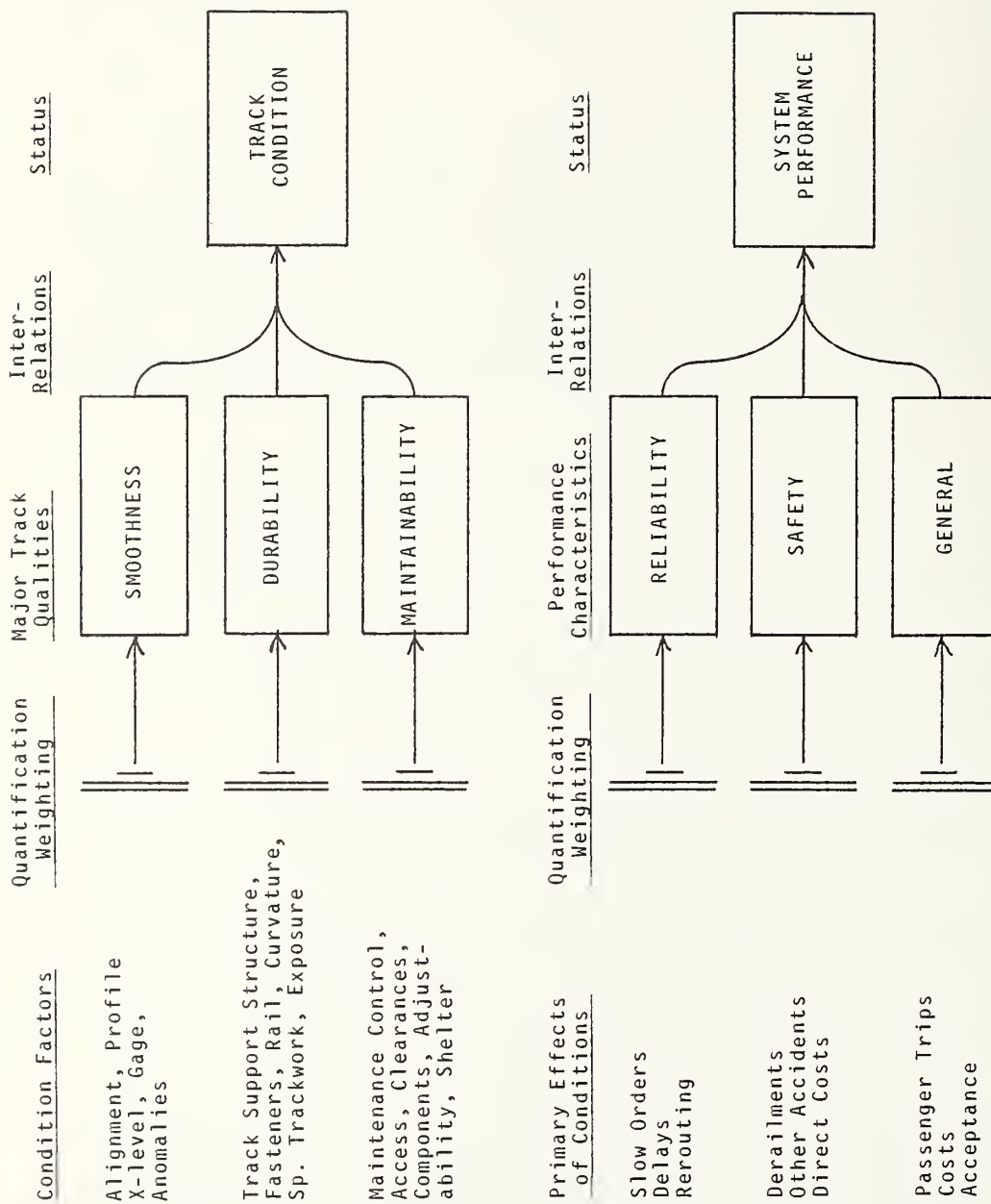


Fig. 17
Evaluation of the Effects of Track Condition on System Performance

The development of detailed procedures to collect and analyze data for rating system performance was beyond the scope of the project. It appears, however, that the procedures used could follow the general pattern and logic of those used in evaluating data for rating transit track condition, with adjustments to suit the type and quantities of data selected.

Plotting the system performance and track condition ratings periodically on a time chart would reveal trends in system performance and track condition. Plotting a series of both ratings, determined for the same times, on a chart (with performance along one ordinate and track condition along the other ordinate) would show the trends in any simple relationship that may exist between the two. It would also indicate some gross effects of changes in track condition upon system performance, but these would not be clear unless the effects of other major factors could be removed from system performance.

The performance of any transit system is affected by some factors peculiar to that specific system and by many other factors that change irregularly with time and vary greatly among transit property locations. The variable factors include: number and conditions of transit cars, availability of parking at outlying stations and in central city areas, cost of gasoline, convenience of locations, appearance of stations, fares, passenger safety, availability of other public transportation, locations of firms that employ or provide services to transit passengers, and local attitudes toward rapid transit.

Unlike track condition, the results of system performance analyses are not expected to be comparable among transit properties. The performance ratings (when related to track condition) could be very useful to local management, as indicators of favorable levels for track maintenance, and as aids in forecasting requirements for major repairs and replacements. On a broader scale, they could become useful indicators of trends and requirements in the transit industry.

5. IDENTIFICATION OF TRACK PROBLEMS

5.1 GENERAL FACTORS

Events, track conditions and items related to track are called problems when they interfere with operations or routine track maintenance, or when their costs are higher than desired. The problems that were studied were identified with the cooperation of the transit industry and were discussed at meetings with members of the Project Liaison Board as well as supervisors and M/W superintendents at the transit properties. Basically the problems are identified areas where improvements are possible. The common factor in these problems is a need to cut costs or at least find ways to help offset the rising costs of energy, materials, equipment and labor.

The events and conditions that will interfere with operations or routine maintenance can almost always be predicted. Most can be avoided through planning and preventive action, while unpredictable emergencies can usually be handled routinely by experienced supervisors and skilled track mechanics who are prepared to perform pre-planned work. In many cases, however, there is room for improvement in the analyses of potential emergencies, the routine procedures for damage control and recovery, the training programs, and the positioning of emergency equipment and supplied.

Most of the items perceived as problems are those that cost more than managers think they should. Many of these items involve routine track design, construction or maintenance; and methods, materials and equipment for this work are not as effective as they would be if additional knowledge were available. The majority of these items are found in track maintenance, since the volume of maintenance work is usually much larger than the volume of design and construction work at any time on a single property.

The problems discussed in this section are identified mainly because they may cost more money or time than is necessary. Each can be considered an opportunity for improvement that will reduce costs or increase ride quality. Other opportunities for improvement have been found during the work on this project that are not related to the perceived problems.

5.2 DESIGN

Transit track designs follow railroad design practices with modifications such as extensive use of guard rails and heavy duty switch components. The designs provide safe and adequate track at reasonable cost; although some problems are inherent in the practice because of differences in the cars and traffic. For example, transit cars cause more vibrations and noise than desired at turnouts and crossings, since the wheels which are smaller than those of railroad cars, drop farther into the flange-way gaps at frogs designed for railroad cars.

Communications. The interchange of information between designers, and construction and maintenance engineers varies considerably and is not always fully effective. A list of "rocks and shoals" to be avoided in track design has not been developed.

Guardrails. The value of guardrails at approaches to obstructions, in tunnels and on elevated structures is not agreed. Railroads have been eliminating guardrails except at frogs and on bridges². Guardrails are shown in Figs. 3, 5 and 10 on transit track.

Tie Spacing. The optimum spacing for ties and direct fixation fasteners to minimize power requirements,¹⁸ wear of rail and vehicle components, and degradation of ballasted track is not known. Tie spacing over 24 inches may contribute to difficulties in maintaining good line and surface of ballasted track.

²AREA, p. 5.

¹⁸Scales, B. T., "Rolling Resistance and Track," Railway Engineering Journal, May 1973.

Restraining Rails. A wide variety of designs are used in the installation of restraining rails. The relative cost and effectiveness of these different arrangements are not known. Restraining rails installed to different designs are shown in Figs. 15, 18, 19 and 20.

Design Loads. A problem has been perceived in the inadequate determination of the loads imposed on transit track and the transfer of loads between track components. However the sizes and strengths of the track components are determined by what is available and suitable among components manufactured for railroads. Although these components are over strength for transit track, they cost less than special components would.

Fasteners. The very large steel plates and heavy double elastic fasteners, used instead of wood ties in special trackwork on concrete slabs/inverts, are costly and may not be advantageous when compared to treated wood ties. In some cases, they have caused stress concentrations that have broken bolts and concrete, thus adding to maintenance costs.

Floating Slabs and "double tie" slabs on elastic supports are very costly and may not be necessary in all cases where they are used to impede the transmission of objectionable vibrations to adjacent structures.

Fastener Adjustment. Available direct fixation fasteners do not have sufficient range of adjustment to compensate for the settlement and warping that occasionally occur in concrete slabs. Designs are needed for special fasteners with a wide range of adjustment that can be used to replace the regular fasteners if and when settlement or warping occur, so that track can be surfaced and lined without costly alterations.

Fig. 18
Guarded Turnout On
Ballasted Elevated Track

The restraining rails ahead of and behind the switch points are lengths of T rail bolted to the running rails in vertical position. The point rails are self guarded, being made of girder rail with built in flangeways.

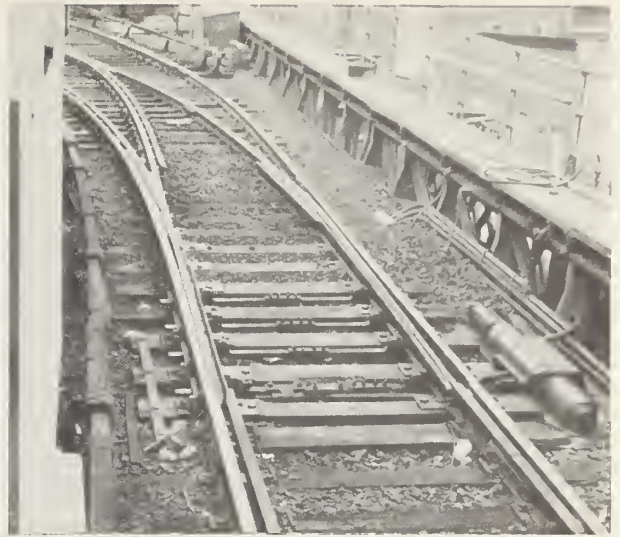


Fig. 19
Restraining Rail on Open
Deck Elevated Track

The restraining rail in this curve is T rail held in vertical position by special tie plates, spacer blocks and large adjustable braces. The track also has guard rails, one showing to the right of the restraining rail.



Fig. 20
Restraining Rail On
Concrete Slab Track

The restraining rail in this photo is installed on braces in a horizontal position. It serves as a guard rail also, and a second guard rail is installed along the high rail to the left.



Suspended Joints have some advantages in ballasted tracks but not in tracks where the rails are supported by slabs or other structures. The practice (vice placing the rail joints on fasteners) introduces extra stress concentrations because of the discontinuities at both welded and bolted joints.

Bolted Joints continue to be the weakest points in ballasted track design as indicated in Fig. 21. Bolted joints will continue to require maintenance earliest and most often until extra support is designed to make the track structure a little stronger at joints than it is between joints.

Stress Transfer. Reliable test data is not available on the transfer of stress between CWR and elevated structures. The deflections of some elevated structures under live loads may contribute to the excessive rock and roll of transit cars traveling at resonant speeds.

Transitions. Jolts are often felt in cars crossing transition slabs between ballasted track and rigid structures, such as shown in Figs. 22 and 23. This indicates that adequate information is not available for designs that will provide a smooth rate of change in track impedance and thus avoid vibrations that cause deterioration of the ballasted track.

5.3 CONSTRUCTION

Quality Control over construction materials and installed equipment is very difficult if actions are left entirely to resident engineers during the on-site construction phases of projects. Quality control is also very difficult when only small quantities of components are purchased for small jobs.

Skills. Construction crews often do not have the skills needed to install track accurately. Training programs are not available for them.

Fig. 21

Deteriorated Track On
Ballasted Embankment

The bolted joints of this track have deflected and pounded the ballast down, making the track very rough. Joint bars are not as strong as the rails they connect.



Fig. 22

Transition From Abutment To
Ballast On Soil Subgrade

Car wheels impact the ballast heavily because of the change in track resiliency when they leave the rigid concrete abutment, and cause rapid deterioration of the track.



Fig. 23

Transition From Abutment
To Ballast on Slab

Although the ballast on slab track is much stiffer than ballast on subgrade, the change in resiliency appears to have been a factor in track deterioration.



Grout Pads. Contractors have difficulty in placing the concrete to support fasteners at correct elevation as indicated by the high grout pads shown in Fig. 24 and the chipped out concrete shown in Fig. 25. Accurate, adjustable templates are needed so that grout pads can be placed for fasteners routinely within acceptable tolerances.

Rail Installation. Detailed guidance is not available for the installation of rails on concrete slabs to accurate line and grade without drilling, shimming or using large amounts of epoxy.

Tolerances specified for track appear to exceed the capabilities of construction crews and inspectors. Good information is not available on the relation of ride quality to tolerances for rail deviations at intermediate and long wavelengths.

5.4 MAINTENANCE

Maintenance Management. There is an underlying need for good guidance on maintenance planning, control, training and teamwork (industrial engineering support). Where maintenance management is good, effective and innovative practices are developed for the efficient correction of problem conditions such as the rail wear shown in Fig. 26.

Many of the best maintenance practices, proven in use by transit systems and/or railroads, are not used by all transit properties. This deficiency will not be overcome by guidance alone, however clear, because of strong local factors that obstruct changes.

All changes are troublesome, even improvements. Some supervisors are too busy and others do not want changes in work that is already adequate and satisfactory to top management. In one case (another study), a below average facility ignored clear guidance on improving maintenance planning and control in order

Fig. 24

Grout Pads Under Fasteners
On Second Pour Concrete

The rail fasteners were shimmed to correct elevation and grout was placed under them, since the large pad of second pour concrete had been installed too low.



Fig. 25

Rail Fasteners Set In
Concrete

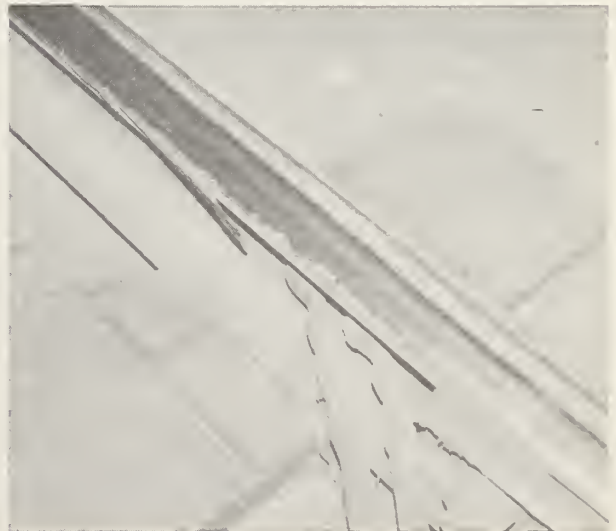
In this case the concrete slab was too high, and some concrete had to be chipped out, so that the rail fasteners could be installed at correct elevation.



Fig. 26

Wear of Low Rail In Curve
In Subway Track

The car wheels have caused wear and metal flow towards the outside of the rail head. As wear continued, some of the flowed metal lip spalled off the side of the rail.



to keep the authorized, higher level positions in the front office rather than the maintenance department.

Rail Wear. Discussions with M/W superintendents indicated that the rapid wear of rail in curved track (including the curved side of turnouts) is a very troublesome problem area in transit track maintenance. An example of severe wear is shown in Fig. 26. The relative benefits of the many different practices used to reduce wear of rail on curves are not fully understood. Information is not available on which to base decisions concerning the most effective combination of practices for specific situations. This problem area was discussed in detail by King in a 1976 workshop on wear control.¹⁹

Corrosion is considerably less of a problem than rail wear, but it is a very common nuisance as noted in ENSCO Technical Note 2-7-9.²⁰ Corrosion adds to maintenance work and costs on all transit properties as indicated in Figs. 27 and 28.

Mud Pumping is not found very often in transit track, because design requirements for drainage, subbase soil, and granular material below the ballast are usually more than adequate. Where mud pumping does occur, however, as shown in Fig. 29 and as discussed in ENSCO Technical Note 1-7-79,²¹ it is very troublesome. Simplified guidance is not available on the use of sand filters and filter fabrics to avoid or correct mud pumping in ballasted track. The use of subballast as recommended in the AREA manual² has not been effective in some cases.

¹⁹King, F. E., "Wear at the Wheel Rail Interface," Seminar 5 Paper, Proceedings of a Workshop on Wear Control to Achieve Product Durability, Defense Documentation Center, Pub. No. AD-A0557712, 1976, p. X136-44.

²⁰Boyd, P. L. and Cunney, E.G., "Corrosion in Transit Track," ENSCO Technical Note No. 2-7-9, 15 June 1979.

²¹Cunney, E.G., "Mud Pumping," ENSCO Inc. Technical Note No. 1-7-9, 1 June 1979.

²AREA, p. 5.

Fig. 27
Corrosion of Rail In
Wet Tunnel

The flashlight at the upper right shines on a rail head that has been partially eaten away by corrosion caused by water dripping from the tunnel roof.

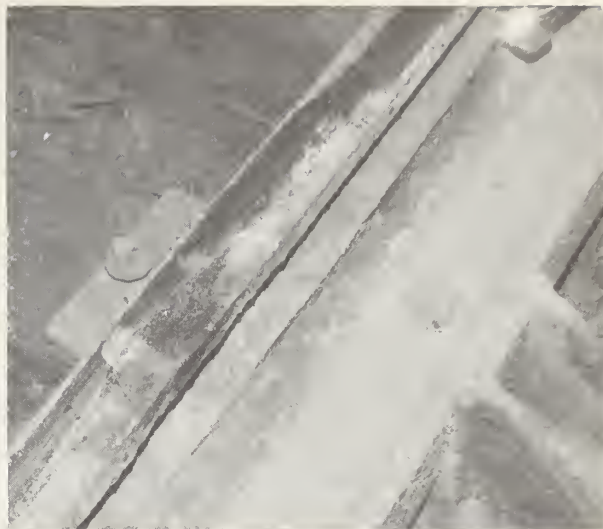


Fig. 28
Corrosion of Rail In
Wet Tunnel

Water dripping from the roof of the tunnel has caused heavy corrosion of the rail head shown in this picture. Nearby rail had been so weakened by corrosion that it had to be replaced.



Fig. 29
Mud Pumping In Ballasted
Track

The white splashes are mud from wet limestone dust and/or subgrade soil that has been pumped up by the action of car wheels passing over saturated ballast.



Inspection Equipment is not commonly available to assist M/W superintendents in determining accurately the relative condition of the track and its rate of deterioration at different locations. Accurate determinations are needed for good decisions on the priority of track maintenance work.

Good inspection equipment is needed by the transit properties to identify changing track conditions, so that they can distribute their limited track maintenance resources most effectively. When a track geometry car was operated over the tracks periodically, NYCTA people were able to identify and plan maintenance requirements very effectively. Space curves were plotted from the track geometry data collected at different times and compared. The comparisons pinpointed areas where track conditions were changing, so that maintenance work could be scheduled before track deterioration became more costly to correct. The wide use of track geometry cars is inhibited, however, by their high cost in relation to the short lengths of most transit tracks.

Inadequate Inspection Tools permit small deficiencies to be overlooked if they cannot be seen easily during a visual inspection. Some commonly-used tools such as the stringline that takes three men to measure rail deviations, and track levels without direct reading bubbles, are cumbersome and slow. Inadequate procedures often result in conditions such as those shown in Figs. 30, 31 and 32 being overlooked although they can be found easily by an observant inspector.

Track Adjustment. Ballasted track on a soil subbase, such as shown in Fig. 21, is difficult to adjust accurately. It requires very frequent maintenance work in some of the transit systems. The adjustment of track on elevated structures with open decks is very difficult and costly. Advanced equipment and techniques are not available for this work.

Fig. 30
Loose Bolts At Joint
In Ballasted Track

Loose bolts allow the joint to deflect under traffic and pound the ballast down into the subgrade. Joint bars wear rapidly when bolts are loose; so they will not hold the rails firmly after bolts are tightened.



Fig. 31
Wide Gap Between Rail
Ends At Bolted Joint

Wide gaps cause accelerated batter of rail ends as car wheels drop into them slightly. They also cause impacts that gradually damage both car and track structure.



Fig. 32
Spall of Rail Surface
At Bolted Joint

The battering by car wheels causes metal to flow toward gaps between rail ends. Hot weather expansion closes the gaps with great force and the lips of flowed metal spall off, leading to more batter in hot weather.



Time on Track. Guidance is not available on the best mix of techniques and the cost-benefits of providing uninterrupted time on track for maintenance work. Delays and interruptions add much to the cost of maintenance.

Tie Deterioration. Wood ties on elevated structures, as shown in Figs. 13 and 15, deteriorate rapidly and are costly to replace. Ties in surface track deteriorate at only a slightly slower rate. A simple, low-cost method is not available for in-place treatments to reduce the rate of deterioration of wood ties.

Joints on Curves. CWR in short lengths is much more expensive to obtain and install than bolted rail. Data are not available on the cost and benefits of using CWR versus bolted rail on sharp curves and short tangents.

Wheel Grinding. Information is not available on the best practices for wheel grinding in relation to rail wear and damage. The "false flanges" that develop near the outside edges of wheel treads are thought to cause rail flow and to damage switch points. Worn flanges are also thought to damage switch points.

Deterioration at Joints of ballasted track is common and often excessive as indicated in Fig. 21. Bolts loosen; fishing surfaces wear and allow differential movement of rail ends; bolts break in some cases; and ballast is forced down into the subgrade material, so that joints are depressed, and the impacts from car wheels become very severe.

Equipment and Materials for transit tracks present some problems. Since the needs of transit properties are small compared to the large requirements of the railroads, manufacturers build track maintenance equipment and tools to suit railroads; and

transit personnel use railroad-type equipment, tools and materials that they find reasonably suitable.

Spares. Track components and spare parts are difficult to obtain in the quantities needed for maintenance work. Non-standard parts are especially difficult to obtain. It is very difficult to obtain satisfactory replacement parts for non-standard track components and components that are no longer manufactured.

Tools. Some of the hand tools available for track maintenance are awkward and cumbersome to use, especially in confined spaces, and some are easily damaged.

Weld Failures. The possible failure of welded rail joints, especially joints that were welded in a track by a thermite process, is a worry. The stress variations caused by car wheels passing over a joint in cold weather may cause cracks to grow from any small imperfection that has been included in a weld.

Broken Bolts. Bolts often break in fastenings for restraining rails and special trackwork, especially when differential movement of track components increases stresses.

Replacing ties embedded in concrete is very slow and costly work in cases where the deteriorated ties are bound firmly in strong concrete. Replacing any tie is difficult where clearances are limited and traffic is frequent.

6. CURRENT PRACTICES

6.1 DESIGN

6.1.1 GENERAL

Transit tracks generally follow railroad designs, since the design consultants have designed many railroad tracks, and most track components came from the railroad industry. The railroad influence can be seen in the trend of new designs away from guardrails and restraining rails, although the engineers and managers of older transit systems are convinced of the advantages of both guardrails and restraining rails.

Routes for new tracks are selected to avoid sharp curves so as to minimize rail wear and noise. A 1000-foot radius is the minimum acceptable for curves in many designs, and efforts are made to install only tangent track in station areas. Flange lubricators are included in most designs to reduce wear and noise on curves, but the use of guardrails and restraining rails has been sharply reduced. Turnouts in new designs have longer radius curves than those in older track systems, a number 15 frog being the minimum at junctions. A 3% maximum grade is achieved in new designs with few exceptions, and grade is generally held to 0.35% or less in station areas. Concern for saving energy has revived interest in designing track with the tops of grades at stations, so that cars will have the assistance of gravity in both acceleration and braking.

Superelevation is usually held to a maximum of 4.5 inches balanced and a maximum of 1.75 inches unbalanced. Rail cant of 1 to 40 is common. Gage on tangent track and wide curves is most often set at 56.6 inches and widened to a maximum of 57 inches on sharp curves. A clearance of 14 feet center-to-center of tracks is common, with widening on curves to suit the clearance envelope of the cars.

Track designs almost always call for a higher degree of precision in installing rails than can be achieved by construction contractors or by the transit property personnel, and the track is accepted and used with long wavelength deviations that exceed specified tolerances but do not affect ride quality very much.

6.1.2 TRACK STRUCTURES

Ballasted surface track design follows the theory of a continuous beam on an elastic foundation.^{2 2} A basic assumption is that the subbase has an elastic response to loads rather than combinations of elastic and plastic responses.

Many assumptions are evident in the numerous empirical equations used to determine the distribution of wheel loads down through rails, ties, tie plates, ballast and subballast to the subgrade; and in the equations used to determine the sizes and strengths needed in the track components. The process as described by Clarke^{2 3} produces safe and adequate design values and is enhanced by the practice of installing a thick subballast of select granular material. This has the effect of raising the bearing capacity of the track structure and making it more uniform where subgrade strength is variable.

Design parameters such as tie spacing and ballast depth are often manipulated without consideration of their effects on the assumed track modulus. Wide tie spacing is often used for economy; and large tie plates are used for strength when smaller, adequate plates are available.

^{2 2}Hetenyi, J., Beams on Elastic Foundations, Scientific Series Vol. 16, Univ. of Michigan Press, 1942.

^{2 3}Clarke, C.W., "Track Loading Fundamentals," Series of 7 articles, Railway Gazette, 1957.

Concrete slab track at grade has been advocated for many years on the reasonable assumption that it will reduce the amount of adjustment and other maintenance work required for ballasted track. However its use has been held back by the lower initial cost of ballasted track and possible problems in adjusting rail on slab track.

As described by Prause,⁷ the design of a concrete slab track on a soil subbase follows continuous beam theory but with a somewhat more elaborate procedure than that used in the design of ballasted track. While tests may show the subgrade strength varies from place to place, a uniform value is assumed for the subgrade modulus, and used in design of the track structure. This can lead to the settling and cracking of some slabs at weak points in the subgrade.

When slab track is designed with wood ties or blocks for rail support, full size (6 x 8 inch or larger) ties or blocks are installed at right angles to the rails, although their beam strength and bearing area are not needed to distribute the loads as they are in ballast.

Ballasted track is no longer designed for use on concrete slab or invert except in the cases of special track work, transition slabs between embankments and rigid structures, and short bridges that join ballasted embankments. Transition slabs are designed with ties and ballast on the assumption that the combination will provide a smooth change in track resiliency from that of a soil embankment to that of a rigid abutment.

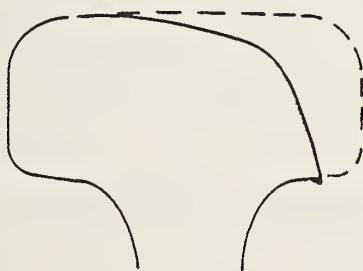
Open deck structures are no longer designed except for long bridges. The designs continue to include full size wood ties

⁷Prause, et al, p. 16.

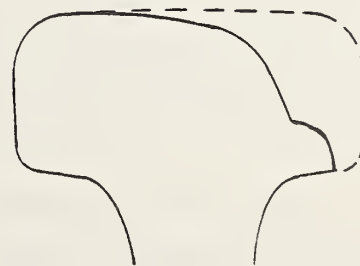
to transmit vertical loads to steel girders and hold track alignment and gage, although the beam strength and bearing area are not needed to spread loads. Rail expansion joints are included in the designs, if continuous welded rail is used.

6.1.3 COMPONENTS

Recent designs call for 115-lb continuous, welded rail. Special trackwork is installed with bonded joints to transfer rail stresses, and insulated joints are bonded and bolted. Restraining rails are not included in designs having only long radius curves except for the guards at frogs, although some M/W engineers consider them valuable in curves up to 1500-foot radius. At one property it was reported that when worn guard-rails were removed and not replaced for a trial period, increased scuffing and low-angle wear was found in the high rails. There were indications that car wheel flanges were climbing the high rail, and the tendency towards derailment had increased. Wear patterns found in curves and turnouts are indicated in Fig. 33. The usual pattern of wear is shown in Fig. 33a. The wear pattern shown in Fig. 33b, found where wheel flanges tend to climb the rail, increases the chance of derailment.



a. Normal Wear



b. Wear Pattern Caused
by Wheel Flanges
Climbing Rail

Fig. 33
Wear of High Rail in Curved Track

In some designs, guardrails are used only on bridges and at locations in tunnels or subways where clearances are critical. In these designs, reliance is placed on the self-guarding effect of equipment below the car body which, if the car derails, will drop down to a position between the rails and tend to hold the car to the line of the track, as it slides along between the running rails. Part of the argument against the use of guardrails on railroad tracks is the belief that they contribute to derailment damage by breaking loose and penetrating cars when hit by car wheels. However it is thought that such guardrails were improperly fastened and poorly maintained, and that the rail ends were loose at joints before car wheels hit them.

Concrete or wood ties are used in ballasted surface track depending on exposure conditions and relative costs. They are generally spaced at 30 and 27 inches respectively. To provide good stability in ballasted track, designs call for a ballast depth of 12 inches under ties with 8 inches of granular subballast on a prepared subgrade of selected soil. Tie plates and pads with cut spikes (and rail anchors where needed) are used in some designs with wood ties on ballast. Other designs call for special tie plates with spring clips and lock spikes or screws. Wood ties are used for special trackwork in ballasted track, and some designs call for wood ties with special trackwork on slab track in order to avoid the problems and high costs that have been associated with the direct fixation of special trackwork. The wood ties are set in concrete with elastic separators to improve resiliency and to facilitate replacement when required.

Direct fixation fasteners at spacings of 30 or 36 inches are used in most new designs to support rails on concrete slabs in subways and on elevated structures. Small floating slabs, called "double concrete ties," have been designed for a few

tracks to dampen vibrations at frequencies that disturb occupants of adjacent buildings.

6.1.4 SPECIFICATIONS

Designers use the material specifications of the American Railway Engineering Association (AREA)² in conjunction with the AREA Portfolio of Trackwork Plans³ for rail and other track components, as these specifications are adequate for transit track with few exceptions. Generally straighter rail is specified than required by AREA tolerances for straightening rail, in order to obtain good ride quality over welded joints.

Data from proprietary designs of manufacturers are used for specifying special trackwork components and other special items such as direct fixation fasteners. This use is based on experience with the products. The designers of new systems or extensions check the operators' recent experience with new products, as well as the established practices of the industry.

Where the products of several manufacturers are acceptable, the specification writer combines and adjusts their product specifications to facilitate competitive procurement. Where only one known item is acceptable, the brand name may be mentioned in the specification with an "or equal" modified in an attempt to obtain competition. These practices have been satisfactory, and the specifications prepared with them have been adequate.

6.1.5 INSPECTION AND TESTS

Requirements for inspection and tests are based on AREA specifications; Federal specifications; specifications of engineering societies and institutes such as the American Society for Testing Materials, The American Insititute of Steel Construction and the American Concrete Institute; and recommendations of various technical committees.

²AREA, p. 5

³Plans, p. 5

No difficulties were seen with quality control in cases where contracts are large enough to bear the expenses of formal inspection and tests, where actions are not left entirely in the hands of resident engineers on the construction phases of the contract, and where there are reports of factory inspection with requirements for additional on-site inspection and tests.

Quality control of welds at joints in continuous welded rail (CWR) is emphasized because of its importance. Ultrasonic inspection of plant welds is usually required not only at the plant but again on site before field welds are made to connect the strings of CWR. Rail ends are inspected both visually and ultrasonically before field welds are made, and the field welds are inspected after completion.

6.2 CONSTRUCTION

6.2.1 TOLERANCES

As noted in the Design Section, Paragraph 6.1, track contracts often called for the installation of rails to tolerances that cannot be achieved by contractors. Often the tolerances are tighter than the tolerances to which the rail is manufactured. Data in Table 5 was taken from the specifications of a recent contract.

The tolerances specified do not appear unusual until one notices that 1/8 inch in 62 feet is approximately one part in 6,000, a little better than third order survey accuracy, and much better than the 3/8 inch in 39 feet tolerance commonly used in rail manufacture. While it is possible to force a rail to a position in the track close to a straight line or smooth curve, even though it was manufactured with a long camber, short bends or kinks are not removed during installation. Unfortunately kinks are introduced in a straightening process commonly used by manufacturers in which a rail is bent at two points to bring it within overall tolerances.

TABLE 6. TRACK CONSTRUCTION TOLERANCES
(Tolerances in fraction of an inch)

Type and Class of Track	Gage Variation	Cross Level And Superelevation Variation	Vertical Track Alignment		Horizontal Track Alignment	
			Total Deviation	Middle Ordinate In 62' Chord	Total Deviation	Middle Ordinate In 62' Chord
Direct Fixation Primary	$\pm 1/8$	$\pm 1/8$	$\pm 1/4$	$\pm 1/8$	$\pm 1/4$	$\pm 1/8$
Ballasted Primary	$\pm 1/8$	$\pm 1/8$	$\pm 1/2$	$\pm 1/8$	$\pm 1/2$	$\pm 1/8$
Direct Fixation Yard & Secondary	$\pm 1/8$	$\pm 1/8$	$\pm 1/2$	$\pm 1/8$	$\pm 1/4$	$\pm 1/8$
Ballasted Yard & Secondary	$\pm 1/4$ $-1/8$	$\pm 1/4$	± 1	$\pm 1/4$	$\pm 1/2$	$\pm 1/8$

Note: Total deviation is measured between the theoretical and actual alignments at any point along the track.

6.2.2 SCHEDULING

No difficulties were seen in the scheduling of track construction except where delays were encountered in the procurement of rail and other major track components, or where delays occurred in tunneling and other track-related construction. Transit properties have overcome the first problem by the early procurement of rail and other long-lead track components and by welding strings of CWR in advance of the track construction. The second difficulty has been reduced by extensive investigation of construction sites during the planning phase of projects and by insisting that construction contractors use critical path scheduling techniques in the management of their contracts.

6.2.3 SPECIFICATIONS

The specifications used for track construction appear clear and adequate except for the very precise track geometry requirement discussed under construction tolerances. Undoubtedly an in-depth study of the specifications for a particular job would produce some slight improvements just as a value engineering investigation of a design will usually produce some improvements or savings. In cases of other construction specifications

studied by the principal investigator, lower bids could be obtained by reducing the quantity of words, simplifying the sentence structure and reducing the complexity of the documents. Contractors were more likely to present lower bids if they did not have to procure and study many reference specifications. Therefore, it is particularly effective to delete reference specifications which would not be enforced by tests or certifications, as in cases where quantities are small or where special quality is not significant.

Quality control is maintained by inspection and test at manufacturers' plants, at fabrication points, and at storage and construction sites. Inspection and testing are included in purchasing and construction contract specifications, in contracts with consulting engineers, in contracts with firms that specialize in providing inspection and testing services, or are performed by transit property employees on site or in their shops.

6.2.4 TRACK CONSTRUCTION

On a new embankment or subgrade, a temporary track may be laid with ties and rails pulled by a tractor or winch from the supply cars on the temporary track. Subballast is then dumped on the track from ballast cars; the track is raised and tamped; and ballast is dumped on the track which is again raised and tamped. The ballast is usually placed in two layers to obtain specified compaction; and a final quantity of ballast is dumped, spread and tamped to fill the cribs and shoulders.

If the right of way has roads conveniently close to it and the ballast is delivered to the property by truck rather than rail, it is usually more efficient to dump the subballast and ballast from the trucks directly on the subgrade, distribute them in layers with a grader, and compact each layer with a road roller

(as in highway practice) before ties are laid and rails are fastened. Either method may be used for ballasted track in a subway or tunnel, depending on haulage distances, clearances and available ventilation.

Close checks are made against survey markers while the ballast is being placed and tamped, in order to keep the track close to its design position. Final track adjustments may be guided by a track liner or track survey equipment as well as by measurements from the survey markers.

In constructing concrete slab track, the concrete for the slab is usually placed with normal highway paving techniques, using the largest pavers or truckmixers and the largest spreader-finishers that the job can accommodate. Special mixes are often used for subway and tunnel slabs so that the concrete can be pumped in for long distances without segregation and loss of strength. Great care is taken in placing and holding reinforcing steel in position so that it will not interfere with fastener bolts, and great care is taken to place the top of slab at design elevation and grade in order to provide required clearance.

Fastener bolts and bottom plates are usually distributed by small motor vehicles well ahead of the rail so that holes can be drilled in the concrete, bolts grouted, and fasteners set in correct position to receive the rail when it is pulled ahead of the cars on pipe rollers.

Large grout pads or a second pour of concrete are often used to provide a surface for fasteners at correct elevations as shown in Fig. 24. Holes are then drilled in the concrete into which the bolts are grouted in proper alignment. Shims are used to adjust the rail to correct surface elevation.

Special trackwork is usually prefabricated by manufacturers or in the transit property shops. It is assembled and checked thoroughly off-site to make sure that all components are complete and fit together properly, and that the overall dimensions of the assembly are within design tolerances. Exceptional care is taken to install each component of a turnout or crossing in the exact position shown by the plans. On site, the work is usually laid out from the 1/2-inch point of the frog which has been indicated by a surveyor with a special survey marker. Ties or fasteners are laid out along the straight track of a turnout, and the rail and other components are installed in the sequence indicated by the manufacturer on the plans. This work requires skilled mechanics and an experienced supervisor, as there are more than 20 major items of work that must be done correctly and in proper sequence. Numerous measurements must be made of offsets from the switch heel and of gage and guard distances to make sure that each component is in correct position to function properly.

6.3 MAINTENANCE PRACTICES

6.3.1 MAINTENANCE MANAGEMENT

6.3.1.1 General

The most important factors in the cost-effectiveness of track maintenance are management skill and enthusiasm. Where management skill and enthusiasm are high there is a continuing search for improvements; and new methods, equipment and materials are tried and accepted or modified to suit the specific needs of the system.

The great range of effectiveness in the maintenance of transit track can be seen most easily in the methodologies used by the transit properties for funding track maintenance. These are generally similar in theory, with long range plans, annual budgets and formal accounting procedures; but they vary

considerably in practice. In the best practices, the costs of track maintenance are considered carefully in relation to both the estimated costs and urgencies of other transit requirements as well as the funds available.

Emphasis is placed on preventive maintenance and the routine correction of deteriorating track conditions at low cost, before these conditions require costly, emergency maintenance as they would if left unattended until they interfered with safe operations. Top management is well aware of the relation of track quality to system performance and is kept fully informed of problems, plans and progress.

The other extreme seen in practice is the allocation of annual funds for track maintenance as a percentage of recorded costs for prior years, without analysis of track conditions and requirements against total system requirements.

Since the quality of maintenance management determines the effectiveness of track maintenance which, in turn, has large effects on the cost and performance of transit systems, important elements of maintenance management are discussed in the paragraphs that follow.

6.3.1.2 Maintenance Organization

A transit track maintenance organization should be able to maintain the track in condition for safe and efficient operations at minimum cost. It should also be able to upgrade the quality of weak parts of the track system, so that future work will be less troublesome and costly.

In order to do this, the organization has to:

- Inspect track adequately.

- Identify current and future requirements, and predict problems.
- Plan, estimate and schedule maintenance work for accomplishment at minimum cost.
- Specify and guide work that is to be done by contractors.
- Perform work efficiently, and control it effectively.
- Train track mechanics, and improve maintenance methods on a continuing basis.
- Provide accurate and timely information to top management.

In order to perform its functions effectively, the track or maintenance of way (M/W) organization should be strong, distinct group with well-trained people who have clear-cut authority and responsibility. If the M/W group is too small to include an adequate engineering staff, it should be provided with competent engineering assistance from another element of the transit property organization or from outside.

The work of the M/W group and its relation to other elements of the transit property organization should be defined in writing. This will avoid misunderstandings over responsibilities, and important work will not be overlooked where track work is intermingled with other functions.

The M/W superintendent should control all track work and the work of all people assigned to his organization. He should participate in overall planning and should have primary authority and responsibility for every phase of the track work.

As a minimum, the M/W organization should maintain the track within the limits set by the property for the speed at which it is operated. Better quality maintenance will correct problems before they cause trouble, slow the rate of track deterioration, and often help to hold down overall costs.

Maintenance should be done at the time it is most cost effective. For example, worn rail should not be replaced until it reaches specified wear limits, unless savings can be made by replacing it at a more convenient time. Thus if a rail is wearing at a rate that would require replacement during very cold winter weather, the work would cost less if done earlier in the fall. At that time, there may be several lengths of rail near the ends of a curve that will not require replacement for several years, but it may pay to replace all the curved rail at one time. Job estimates should show if this will reduce overall costs.

6.3.1.3 Maintenance Planning

Planning includes:

- Evaluating present and projected levels of traffic density and speed and other factors that affect track quality requirements and track condition.
- Determining track conditions from study of inspection reports, work plans and other information.
- Projecting changes in track condition and identifying future problems.
- Determining the relative urgency and importance of maintenance requirements.
- Developing plans for keeping track in satisfactory condition at minimum cost.
- Determining the relative cost-effectiveness of alternatives that become available in track maintenance methods.
- Obtaining estimates of availability and commitments on future resources for track maintenance.
- Scheduling maintenance jobs and integrating on-track time with operations so as to minimize costs.
- Estimating time and costs.
- Detailed planning and scheduling of maintenance jobs.
- Reviewing results in order to improve plans and methods.

Since maintenance is planned for the quantity, type and condition of the track and the requirements of projected traffic, accurate inspection measurements and records are essential. Accurate measurements of conditions and records enable the M/W superintendent to identify trivial problems that may lead to great expense or damage if not corrected.

Maintenance requirements are identified by inspection of the track and from reports of track deterioration or problems. Maintenance requirements should also be derived from the evaluation of data in inspection reports, equipment records, projected traffic schedules, plans for new equipment and construction, and other documents. Study of these data enables M/W engineers to predict requirements long before they can be identified by inspection of the track.

Priorities of the maintenance requirements are determined by evaluating their effects on safety and production if left unattended, and by estimating how the costs and difficulty of the work may increase as the work is deferred.

Maintenance Categories, into which the work is usually divided, reflect the urgency and importance of the individual jobs. This helps to ensure that critical conditions will be corrected before they become dangerous and that other work will be done at the most suitable time to avoid track troubles and minimize costs.

Categories of maintenance work that are often used include: preventive maintenance, routine maintenance, emergency maintenance, and deferred maintenance. Some activities also use the categories of major repairs (separated into discretionary and non-discretionary maintenance), alterations or improvements, and housekeeping. The first three categories are generally

well understood. Deferred maintenance, however, is often thought to include desirable work as well as necessary maintenance. The former would be better placed in the category of major repairs, under the heading of discretionary maintenance.

Scheduling outlines the management decisions that identify work, set its priorities, and designate when it is to be done. Scheduling is an effective and essential element in the maintenance system. It communicates to everyone concerned his part of the maintenance work. It also provides concise management information on maintenance efforts and checkpoints for measuring output against plans.

Schedules should include ample allowance for urgent requirements that cannot be foreseen in detail much in advance. This emergency allowance should include large allowances for start-up time; because emergency maintenance almost always interrupts other work, requires some materials or tools that are not at hand, or lies a considerable distance away from the location of scheduled work.

Scheduling track maintenance work is usually done in the following sequence:

- List all foreseeable work items.
- Balance projected work load against resources.
- Note conditions that affect the work.
- Plan jobs to suit conditions.
- Estimate man-hours for each job.
- Balance available man-hours and job estimates.
- Enter jobs and man-hours on calendar charts (schedules).
- Collect cost and time data to improve estimates.

The complete maintenance schedules usually include a long-range plan (about 5 years), an annual or 16-months schedule, an intermediate schedule for 3 or 4 months and a short-term schedule covering several weeks. In this order, the schedules reflect an increasing knowledge of factors that affect the availability of labor, materials and track time, such as vacation plans and estimated traffic.

Scheduling is essential to cost effective maintenance planning and control, but it cannot be done effectively unless all of the related functions of maintenance management are also performed effectively.

6.3.1.4 Maintenance Control

Maintenance control involves the measurement, evaluation and correction of work. It ensures that planned work is done efficiently; that proper adjustments are made for unforeseen conditions; and that there is good feedback of information and ideas from track mechanics, so that work methods and estimates can be improved.

The primary control in maintenance is direct supervision. The supervisor plans the work in detail, discusses it with and instructs track mechanics, observes the work in progress, corrects it when necessary, and checks the completed work. Track maintenance work often has to be done without direct supervision, however, as numerous small maintenance jobs are performed by a mechanic working alone or with a helper. Accordingly other controls should be used to obtain good, uniform quality in the completed work.

In addition to direct supervision, maintenance controls include:

- Detailed scheduling.

- Assignment of a qualified track mechanic to every job.
- Use of maintenance standards.
- Collection of time and cost information.
- Inspection of completed work.
- Review of inspection reports.

The development of maintenance standards helps planners, supervisors, and mechanics. Standardization of procedures and available equipment for both routine jobs and emergency work will enable supervisors to spend more time and thought on unusual problems.

The collection of time and cost information is a function that should not be slighted. Time and costs of labor, material, equipment, engineering, and overhead should be reported in detail. This permits estimates to be checked and estimating procedures to be improved; it pinpoints areas of unusually high or increasing costs where improvements should be sought in maintenance techniques; and it provides management with needed information.

Detailed inspection of all completed work ensures that the work was done in the right place and that the completed work meets the maintenance standards. When the supervisor knows the work required and keeps simple, accurate records of job assignments by location and time, he can spot-check finished work when convenient. He can tell the quality of the track mechanics' work over a period of time by observing the results and by comparing the results to other maintenance work that has been done and to standards that have been developed. He can raise the quality of the work by providing additional instruction and better materials or tools, or by allowing more time. Conversely, when the work quality exceeds needs, both time and materials may be reduced.

Reviewing inspection reports helps the M/W superintendent and engineers to determine the overall quality of track work and changes in track condition. It also helps to indicate where additional guidance is needed in the form of plans, schematics, checklists, written procedures and discussions.

6.3.2 METHODS

In general the M/W departments follow the best maintenance practices developed in the transit and railroad industries. Specific practices that are considered advantageous for transit track maintenance but which are not in full use are listed in Appendix A. As noted in that appendix, these practices were discussed in the track maintenance workshop.

Many variations are found in track maintenance practices because of specific local conditions. These include the original construction, age of the track, traffic levels, climate and track exposure, availability of qualified maintenance contractors, large variations in local costs of labor and materials, operating practices that restrict time on track for maintenance, union agreements requiring special practices, and public preferences. For example, climate may have large effects on durability as seen in the different rates of deterioration of wood ties in Boston and Miami. It also has large effects on the productivity of a track maintenance crew working on an exposed track during winter weather.

6.3.3 EQUIPMENT AND MATERIALS

The large and expensive equipment used in railroad maintenance is generally not cost-effective on transit track because of the relatively few miles of track to be maintained, small clearances and very frequent traffic. There are some exceptions where railroad-type equipment will fit and is used; these occur where railroad ways were taken over and are operated by the properties. In all cases where large maintenance equipment

is purchased, its utilization rate has to be high enough to cover amortization, operation, maintenance and storage costs by savings in labor and additional power tools.

In addition to many small power tools such as saws, drills, wrenches and hoists, the equipment used by transit properties includes: cranes, rail benders, tampers, liners, specially equipped work cars, shop equipment such as milling machines and grinders, portable rail grinders and grinding trains.

Two of the transit properties have ordered special welding trains that have a record of producing very high quality flash-butt welds. These are expected to provide savings in the large numbers of field welds that are planned in the conversion of the track to continuous welded rail. They also are expected to produce higher quality welds than are possible with thermite processes.

The materials used by the transit properties are similar to those used by the railroads. In recent years, efforts have been increased to standardize on track components and materials that are in common use in the local area of each transit property, so that resupply will be less difficult. The better quality materials such as manganese steel for frogs and points, hardened steel rail and high-strength track bolts are preferred because of their longer useful lives in locations where high frequency traffic and other factors make replacement difficult and costly.

6.3.4 INSPECTION

Standards are recognized as necessary by all of the transit properties. They conform with the recommendations published by APTA¹ and tend to follow railroad maintenance practices² and

¹APTA, p. 30.

²AREA, p. 5.

Federal standards.¹ Some of the properties have developed their own standards with similar but stricter requirements. Transit track generally exceeds Federal standards¹ where safety is concerned, as in the replacement of worn rails and defective ties.

Inspection is difficult because of the frequency of traffic. On many of the transit properties, an inspector (trackwalker) is supposed to make minor adjustments and repairs while inspecting the same length of track repeatedly. Experience is not shared very well, and judgments are not improved by cross-checking and discussion. Some inspectors tend to be very forgiving of defects they would have to correct themselves, such as loose bolts and loose tie plates. Generally the only regular inspections are those made by the trackwalkers and their supervisors. Sometimes a surveyor may be called in to check a major realignment if it seems necessary. A track level, gage and stringline are used at times, but many adjustment needs are judged by eye.

Rail flaw detection services are used, and a few transit properties are planning to purchase equipment for repetitive track geometry measurements to aid inspection and maintenance planning.

6.4 EUROPEAN PRACTICES

Advanced European practices and other practices that would be new and potentially valuable to U.S. transit systems are discussed in Section 7. The practices discussed in this Section are more conventional. They have been effective for many years, but some of them will be displaced by newer methods as their reliability is proven.

¹Standards, p.3.

6.4.1 INSPECTION

In order to obtain thorough and uniform information on track conditions and trends throughout the system, London Transport has developed the practice of having complete semi-annual inspections conducted by a specially trained and experienced team of inspectors. These inspections are in addition to inspections by trackwalkers, supervisors and others. The inspectors are completely separate from other elements of the M/W Department. They use tools to expose and to measure track conditions, and follow a standard check list when inspecting track components and all wayside features, such as drains and fences. This helps to reduce bias as far as possible and provides a nearly uniform base for the inspection of all divisions of the system. The inspectors are called "track markers" because they rate each track feature in each 400 meters of track according to a standard condition scale, total their marks, and assign overall marks to each length of track. This not only provides good comparisons of conditions and trends in the different divisions, but arouses competitive interest in track maintenance among track supervisors and mechanics.

6.4.2 RAILS

London Transport uses a bull-head rail but expects to change gradually to T-rails as the former becomes relatively more expensive. Transit systems on the Continent use T-rails. The 60-foot rails of London Transport are shop welded into 300-foot lengths of CWR, as these are the longest lengths of welded rail that can be moved conveniently through the curves and interchanges of the track system. The CWR is connected in the track with bolted joints into nominal lengths of 0.5 mile. The fishing surfaces of both the joint bars and the rails are machined for a smooth, tight fit. High-strength bolts are used, and they are oiled and torqued regularly to specified tension. The rails are loosened to relieve stress

and are set to their nominal lengths at mean temperature in the early spring of every year, to minimize the change of buckling. Only one joint failure has been reported in 30 years, and the bolted joints at 300-foot intervals are considered very convenient for track maintenance work. In curved track of less than 1000-foot radius, CWR is not used. Sixty-foot rail lengths are connected by bolted joints. In the early spring of each year, these joints are regapped to minimize the possibility of buckling and to reduce rail-end batter and noise.

A separate rail is installed along the centerline of the track for return power. This crowds the working space available for track maintenance, but it reduces corrosion of the running rails and fasteners. It also simplifies the installation of track signal circuits.

Most of the European transit systems are using field-welded joints to connect lengths of shop-welded CWR. Thermite welding is widely used, but electric arc welding is used in Stockholm. In the electric arc method, large copper heat sinks are clamped to the rails, and an asbestos-copper form is used at the base of rail to minimize extrusion of weld material. Good results are claimed with both methods, with very few weld failures in any one year.

Check rails (restraining rails) are commonly used on curves below 1000-foot radius, and flange lubricators of many types are used on sharp curves. In a few cases, water sprays are used to reduce wheel squeal, although the sprays were thought to contribute to shelling of the rail surface.

Rail grinding to remove corrugations is common in European transit systems. Slip stones are used in some systems and rotary grinding stones in others. Corrugations were thought to be more common in rail on concrete ties than on wood ties.

6.4.3 TIES AND FASTENERS

Ballasted track continues in wide use because of its relatively low cost and its convenience for maintenance work. The emphasis in recent years has been on increasing the ballast layer and compacting it to reduce the frequency of maintenance work.

The high value of salvaged wood ties (said to be as high as 70 percent of the cost of new ties in Germany) tends to favor the use of creosoted wood ties where good wood ties can be obtained, and where weather and drainage conditions do not encourage excessive growth of rot organisms.

7. ADVANCED TECHNOLOGY

7.1 GENERAL

Among the concepts and methods included in this section are some that have been in use for years in other industries or in other countries. They are included because they are not in use in U.S. transit systems and may be of value when they are modified to suit transit system requirements.

Recent advances in track technology have not been the result of sudden breakthroughs or the exploitation of new discoveries in basic science. Advances of that sort were made years ago in the early days of transit track development. Recent advances in track technology have come about slowly, as the result of persistent effort and many investigations of specific track conditions that were perceived as major problems or opportunities for improvements. In the U.S., as noted in Section 2, this effort has been aimed primarily at problems associated with very heavy wheel loads and increasing density of traffic on railroad tracks. The results have been of only minor value to transit track.

European and Asian railroads and transit systems have wheel loads and traffic frequencies that are reasonably close to U.S. transit conditions, and the results of their research are of great interest. Conversely their ratio of material costs to labor costs has been much higher than in the U.S. until recently, and the use of their research products is often labor intensive or requires high levels of skill.

The advances that have been significant to transit track have been in process for many years, but only recently have continuing research and tests made them very reliable and

effective. These advances include some general improvements of value on any type of track such as:

- Continuous welded rail (CWR) to reduce maintenance and noise at rail joints and improve ride quality.
- Rail flaw detection equipment to find small and internal defects in rail early, so that corrective repairs can be made before damage occurs.
- In-track welding methods, first thermite processes and lately, flash butt welding, to permit conversion of track from bolted joints to CWR without removing and replacing rail.

The advances listed above are well known to transit engineers and are being applied where appropriate throughout the industry. Ultrasonic rail flaw detection services have been very effective in helping to uncover and eliminate small or hidden rail flaws.

Many advanced practices were noted in the London Transport system or in systems on the Continent that were visited by representatives of London Transport International Services (LTI). In some of the transit systems, the introduction of block-jointless track signal circuits has enabled them to remove insulated joints completely, and the rails have been welded together continuously through turnouts and crossings.

In the 1930's high-manganese steel rails (13% to 14% manganese) were introduced in England for use on sharp curves and were used on a 360-foot radius curve in the London subway.

The manganese steel extended the life of the rails greatly; but problems were encountered in drilling the tough steel, and its high electrical resistance was objectionable. When the rails had to be renewed during World War II, manganese steel rails were not available, and hardened carbon steel rails (with lubricators) were substituted and have been used on the curves since then. While the manganese steel rails cost approximately five times as much as regular steel rails, the costs of rail renewal and the cost of interference with operation make them appear marginally favorable (if available for use on sharp curves with high density traffic).

When it is necessary to use temporary joints before strings of CWR can be welded together on the Hamburg and Stockholm systems, the temporary joint bars are clamped to the rails with heavy duty C clamps. This avoids the need for drilling the rails and bolting the joint bars to them.

A simple technique for transposing the running rails has been developed in Stockholm. The running rails are unfastened, and their ends are threaded through a "thimble" device containing pairs of rollers which is held in the air by a crane. The crane then backs down the track, and the rails are lifted by the "thimble" and deposited on the opposite sides of the track.

Grinding wheels to a worn-wheel profile was said to have increased the intervals between wheel grindings from 155,000 to 370,000 miles in Hamburg and will probably be increased to 435,000 miles. The use of rheostatic braking at speeds above 1.9 miles per hour was said to have virtually eliminated wheel flats on the same system.

7.2 BALLASTED TRACK

Many advances in track technology have been made specifically to improve ballasted track. Concrete ties have been fully adequate for transit track service for many years, although some designs failed in railroad service as recently as five years ago.

New developments that are potentially useful to transit properties with ballasted track are:

- Lime injection to strengthen weak subgrades where drainage improvements and other stabilization methods are not adequate.²⁴
- Filter cloths to protect fine soil subbases from the effects of water and vibration and prevent mud pumping, as an alternative to the installation of a sand filter layer.²⁵
- Ballast compaction to increase the stability of ballasted track and reduce its rate of deterioration under traffic.²⁶

Interest in lime stabilization techniques developed among American railroads as a result of successes observed first in building construction and later in highway construction in the Southwest, where expansive soils have caused serious foundation problems and damage to structures. Much work has been done

²⁴Blacklock, J. R., Lawson, C. H., and Ledbetter, R. H., "Handbook for Railroad Track Stabilization Using Lime Slurry Pressure Injection," Graduate Institute of Technology, Little Rock, AR, and U.S. Army Engineer Waterways Experiment Station, Report No. FRA/ORD-77/30, Rev. Apr 1979.

²⁵Schaaf, H. L., "Investigating and Choosing Engineering Filter Fabrics," Railway Track and Structures, June 1979.

²⁶Reissberger, K. H., "Means and Methods to Increase Track Stability," Annual Technical Congress, American Railway Association, Chicago, IL, Mar 1974.

to adapt lime stabilization techniques to railroad requirements. Filter fabrics have resulted from work done in Europe and the U.S., and ballast compaction was developed in Europe and later demonstrated on U.S. railroads by the Federal Railroad Administration (FRA).

For many years a great amount of European research has focused on developing ballasted track that will not require frequent adjustment under high speed traffic. Some of the effort has been aimed at reducing the traffic forces that disturb track, by building smoother rail and designing smoother transitions between curves and tangents. Some has been aimed at providing more resiliency in fasteners, so that larger proportions of the forces that disturb track will be absorbed above the ballast. And some of the effort has gone toward strengthening the subbase and subsoil, and increasing the density of the ballast layer in order to give the track more resistance to the forces that disturb it.

Studies by the British Railways Board Research Department²⁷ showed that a much thicker track structure than indicated by elastic foundation theory²² is needed to avoid early failure of ballasted track on weak soil formations. They found that a subballast layer (compacted granular subbase) as thick as 5 feet would be necessary in some cases. A thick layer of ballast would have the same effect, of course, as shown on the Stockholm system. Ballast is relatively cheap in Stockholm because of the large quantity of spoil from tunnel excavations though sound rock, and ballast is placed in compacted layers to a depth of 20 inches even over good formations. This practice was said to produce a very firm track that seldom requires maintenance.

²⁷Heath, D. L. Shenton, M.J., Sparrow, F.W. and Waters, J.M., "Design of Conventional Rail Track Foundations," Proceedings Institution of Civil Engineers, London, Paper No. 7468, 1972.

²²Hetenyi, p. 65.

Since the forces that damage track increase approximately with the square of the traffic speed, it has been very difficult to operate railroads at speeds much higher than 90 miles per hour, even with lightweight cars, without requiring excessive track maintenance. However persistent research efforts have gradually produced high speed track with reduced maintenance requirements. While transit systems do not operate at very high speeds, the results (particularly strengthening the track subbase and increasing the ballast density) have been valuable to them. Mr. Woods, of LTI reported at the Transit Track Seminair (Appendix F) that European transit authorities have built very strong track subbases and have installed thick layers of compacted ballast under the ties. The results lead them to expect that major track adjustment and resurfacing will be reduced to a frequency of about once in ten years.

Ballast compaction has been found very advantageous in Europe for maintaining old track as well as in new construction.²⁶ In the existing track, the ballast is compacted in the cribs and shoulders after the track has been disturbed by resurfacing.

When track is resurfaced without ballast compaction, the ballast is tamped under the ties near each rail, after the track has been raised and adjusted. Each tie is then left sitting on two pedestals of compacted ballast, while the ballast in cribs and shoulders is relatively loose. Since the pedestals of tamped ballast under the ties are not completely restrained by the loose ballast in cribs and shoulders, the ballast tends to shift laterally, and the ties settle unevenly under traffic even when subgrade conditions are very good. This effect is

²⁶Reissberger, p. 91.

severe when all cars have similarly dynamic characteristics, so that they all respond similarly to small irregularities and soon pound large irregularities into the resurfaced track even when wheel loads are relatively light. When the ballast in cribs and shoulders is compacted, the ballast tamped under ties is restrained, so that it cannot move laterally, and ties cannot settle appreciably.

In FRA tests, ballast compaction was found to increase the lateral resistance of freshly disturbed track by approximately 40 percent. It also reduced the vertical settlement of ties at bolted joints that had been disturbed by resurfacing work, by 15-to-20 percent.²⁸ When an LTI representative visited the Hamburg transit system, he was informed that ballast compaction had definitely helped to reduce track maintenance requirements. Keel plates are fastened to the bottom of ties on the Hamburg system to increase the lateral stability of the track on curves, and major resurfacing has been reduced to less than once in ten years.

A ballast stabilizing compound developed under FRA sponsorship was tested in 1969 and found to increase greatly the resistance of ties to vertical and lateral loads.²⁹ The compound is sprayed on washed ballast after the ballast has been placed on the roadbed and then cured with ammonia. This leaves the open ballast glued together with an elastic, rubber-like material.

In tests performed in 1974, the open, glued ballast was supported directly on a subgrade of clay and clayey silt without the protection of an intermediate sand filter layer or filter cloth.

²⁸ Cunney, E.G., May, J.T. and Jones, H.N., "The Effects of Accelerated Ballast Consolidation," ENSCO Report, FRA-OR&D 76-274, March 1976.

²⁹ Magee, G.M., et. al., "Stabilized Ballast Investigation," AAR Report No. DOT-FRA-ONSGT, Aug., 1969.

After a heavy rain, fine material was pumped up through the large interstices of the ballast, and the roadbed failed without a true test of the stabilized ballast. This test indicated that a layer of filter sand or filter fabric and granular subballast is required between the stabilized ballast and a clay subbase in order to prevent mud pumping and early failure of the stabilized ballast. When properly installed, the stabilized ballast can be expected to have good resiliency and resistance to deformation caused by traffic and thus reduce the frequency of track maintenance.

In later tests,³⁰ a layer of regular ballast was placed on top of the stabilized ballast, under and between the ties, to facilitate adjustment of the track in case of settlement. As a result of traffic, the regular ballast layer shifted laterally on top of the stabilized layer. This shifting might be prevented by bracing the track on curves or rolling irregularities into the stabilized layer to resist shear.

Japanese engineers have developed a ballast mat made from chopped scrap tires that is placed under ballast supported by a concrete slab or tunnel invert.³¹ The mat increases the resiliency of the track towards that of a track on an embankment, and the practice could be of value where ballast is used on concrete transition slabs between embankments and slab track or abutments. The mat also reduces the crushing action on the ballast that occurs between concrete ties and slab when

³⁰Weber, J.W., "Evaluation of Improved Track Structural Components under Sub-Arctic Conditions," Portland Cement Assn., Report to the Federal Railroad Adm., No. FRA/ORD-79-01, Jan. 1979.

³¹Miyamoto, T., Watanabe, K., and Aoki, M., "Development of Unconventional Track by JNR," Rail International, March 1975.

passing trains exert rolling loads. The crushing effects are smaller with wood ties on the ballast, especially when the rail is free to float without lifting the ties; but the ties still seem to wear more rapidly than they do on ballast on soil embankments. Rubber mats have been placed under ballast in the subway stations of the Edmonton System to help reduce noise.

Brief notes have been seen³² on what appears to be a very favorable concept for providing better support to rails and more lateral stability than ties normally do in ballast. The concept is a precast concrete panel in the form of a hollow square that takes the place of four concrete ties, with about the same amount of material in it as in the four ties. The panels are placed end to end, and the rails are supported continuously on the longitudinal sides of the panels which are about 16 to 18 inches wide, while the transverse sides (in the normal position of cross ties) are about 8 inches wide. The hollow panels act as a pair of parallel beams supporting the rails with additional bearing area at the joints provided by the transverse sides. This extra bearing area should compensate for the deficiency of weakness at joints in beams and slabs on embankments which otherwise results in large forces that damage the subbase. The concept was developed in Russia about 1974, and panels were placed in a test track near Moscow, but no detailed reports have been found.

Wood ties are being used less and less in Europe because of their high cost in relation to concrete ties. They are used often in temporary installations and in areas where equipment cannot be used for track maintenance, as their light weight is an advantage when manual methods are used for track adjustment and repair. Elastic fasteners are generally used with wood

³²Meacham, H.C., "Non-Conventional Track Research Needs Over the Next Fifteen Years," Railroad Research Study Background Papers, Association of American Railroads, R.B. Cross Co., 1975.

ties in Europe. They are also used in a few cases in U.S. transit track as shown in Fig. 34.

7.3 CONCRETE SLAB TRACK

The earliest concrete slab tracks at grade on record were short sections built on the New York Central in 1909. Presumably these early tracks failed as did generations of slab tracks as late as 1977 because of pull-out or breaking of fastener bolts or adjacent concrete. The high stiffness, low damping and heavy mass (relative to wood ties) of a concrete slab all tend to increase dynamic loads at high frequencies; and when fasteners prevent the flexing action of rails that normally reduces stresses and distributes loads, very high stress concentrations result.

Early in the century, U.S. railroads and transit systems found that they could successfully fasten rail to wood ties that were bolted to concrete slabs in tunnels and on bridges, and that these fastenings were adequate for low and medium traffic speeds. However research on direct fixation of the rails to the slabs continued, especially in Japan and in European countries, as it appeared to offer reduced maintenance and increased stability for high speed traffic and as wood ties are relatively costly in those countries. The fastener problems have been overcome with modern double elastic fasteners that allow limited rail movement and have spring rates that are not too high for the strength of the fastener bolts. In Japan the emphasis has been on reducing the frequency of high cost maintenance while retaining a ride quality similar to that of ballasted track. A very interesting development has been a double slab track with a layer of elastic material between the slabs.³¹

Short concrete slabs on elastic supports called "double ties" are shown in Fig. 35 in position on track of the Toronto

³¹Miyamoto, et al, p. 95.

Transportation Commission, before installation of rails. These slabs are designed to dampen vibrations that would bother occupants of adjacent apartment buildings. When installed, the CWR will be placed above the slabs on the adjustable "lift plates" or chairs shown in Fig. 36; then connecting welds will be made, and insulated joints will be installed. Final adjustments will be made to correct line and profile; the rails will be blocked against the tunnel wall and curbs to hold them in correct position; plugs will be removed from holes cast into the small slabs; fasteners will be attached to the rails with bolts hanging into the holes; and the bolts and fastener base plates will be grouted permanently. Similar small slabs are in use in the Atlanta system.

Because of their initial cost, slab tracks are built at grade in Europe only in locations where the subgrade conditions are very poor or where it is difficult to perform the routine maintenance normally required on ballasted track. However some of the slab track built in Europe appears to be elaborate and expensive when compared to designs that have proven to be effective for airfield and highway pavements.

The concrete slab track at Adele Station in Germany is described³³ as consisting of 9 inches of continuous reinforced concrete on an 8-inch thick layer of insulating, lightweight concrete having a plastic additive. Under this is an 8-inch thick layer of lean concrete, on an 8-inch layer described as mineral concrete. This 33-inch thick structure is supported on a prepared soil subbase protected by deep field drains. A similar multi-layer structure is described at Rheda Station, with concrete ties on top of the continuous reinforced slab and concrete fill between the ties.

³³Eisenmann, J., "Railroad Track Structures for High-Speed Lines," Proceeding Paper, 1975, Railroad Track Mechanics and Technology, Kerr, A. D., Editor, Pergamon Press, 1978.

Fig. 34

Elastic Fasteners on Wood Ties

The spring clips hold the rails firmly to the tie plates and tie. They exert enough longitudinal restraint so that rail anchors are not needed. Large screws are used at the insulated joint where there is not enough clearance for the spring clips.



Fig. 35

Small Concrete Slabs on Elastic Supports

These small concrete slabs are used to reduce traffic vibrations in areas where the vibrations would otherwise annoy occupants of nearby buildings. Each slab has holes cut in it for the bolts of four rail fasteners.

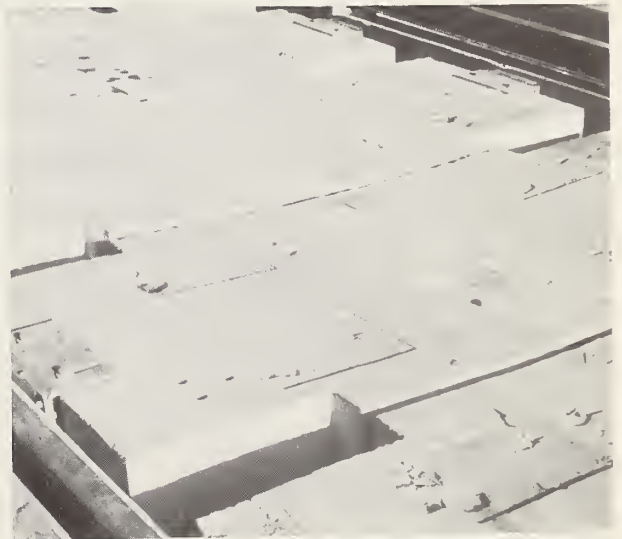


Fig. 36

Temporary Rail Supports

These "lift plates" or "chairs" were made from salvaged tie plates by the Toronto System. The threaded bolts can be adjusted to hold rails in correct position, so that fasteners can be attached to the rails and their bolts can be grouted into holes in the slabs.



Slab track that provides continuous support to the rail has been built in many locations under a British design. It has been used in several countries for railroad track, and for mine haulage track in one case in the United States. This design places the rails on continuous elastic pads on a continuous concrete slab, and holds the rails down with spring clips attached to fastener devices embedded in the concrete.³⁴ The design permits the use of slip-form concrete pavers which should offer substantial savings in construction compared to other methods. However, the continuous slab may introduce some new problems, as adjustment of the rails will be difficult if the slab settles or warps at weak points in embankments or transitions from rock to soil in the subbase material. In this design, the reinforcing steel is welded together continuously, but is not prestressed or post-tensioned, and the concrete can be expected to crack when adjusting to large temperature changes. Although the reinforcing steel will hold the cracked concrete closely together, so that vertical shear will be transferred across the cracks, moment will not be transferred across a crack effectively, and this results in higher loads on the subbase at cracks.

The Pandrol Company has recently designed a patented, adjustable fastener for the spring clip that allows 0.35 inch of lateral rail adjustment and 0.59 inch of vertical adjustment. The lateral adjustment is made by rotating an insulated collar that has a different wall width on each of four sides, so that the distance between the clip holder and the rail is set by the selected wall width. Vertical adjustment is made by turning an outer insulated collar that rests between the spring clip and the rail base, that has a different wall depth on each of four sides. The rail elevation is set by the selected wall depth, and shims are placed beneath the rail before the spring clip is replaced in the holder.

³⁴Berry, J.S., "NZR's Kaimai Tunnel Nears Completion," Railway Gazette, Oct 1977.

8. OPPORTUNITIES FOR IMPROVEMENTS

8.1 POTENTIAL IMPROVEMENTS

As discussed in Section 5, every event or condition that is perceived as a problem also represents a potential opportunity for improvement. In addition to the potential improvements that arise from problems, a few potential improvements are found when normal practices are examined against the technology available from other industries and other countries.

Some of the items perceived as problems (such as the wear of rail on curves) were seen to be problem areas that contain many individual problems, some unidentified. In addition, the problems identified in these areas varied greatly in importance from place to place and time to time. It soon became apparent that overall solutions could not be expected. A very orderly and systematic examination would be necessary to isolate specific problems and opportunities for improvements from these areas, so that they could be evaluated individually. It appeared advisable to dissect a few simple problems in order to develop a systematic procedure for examining them before going deep into problem areas.

Few transit track problems are clear and uncomplicated. One seemingly simple example was seen in the many loose bolts found in joint bars in one line of a transit system. Only a few of the loose bolts were visible at a glance; others were detected by tapping them with a small hammer. The loose bolts are supposed to be kept tight by a trackwalker (inspector) who does minor work of this sort in addition to inspecting the track.

The supervisors' answer to the loose bolt problem (in more forceful language) was, "Holler at the trackwalker."

The experience of the investigators with problems of the same general nature indicated that if this were an effective answer, the bolts would not be loose.

The simple answer to the apparently simple problem of keeping the bolts tight is to tighten them periodically with a wrench. Unfortunately this answer begs other questions such as, "Who should do it?", "How often?", "What kind of a wrench?", "How do we pay for the work?", and most significantly, "Why aren't the bolts kept tight now?"

Since answers were not ready for these and similar questions, several simple problems were examined in order to develop a check list that could be considered in every case and would help provide the information needed for good decisions. This list is shown in Table 7 as applied to the loose bolt problem.

Obviously much detailed local information would have to be collected and considered before a good decision could be made in the case of the loose bolts or any other small track problem found at a transit property. Although time was not available in this study for detailed investigation of the local factors that affect small problems, the systematic approach was helpful. Keeping it in mind assisted investigators to consider all aspects of perceived problems, to avoid invalid conclusions, and to improve their understanding of the complexity of problem areas.

A similar systematic approach was developed for the consideration of problem areas, with a breakdown of an area into identifiable problems and sub-problems as outlined in Table 8.

Numerous problems and practices were examined during the course of the project. The potential opportunities for improvement

TABLE 7. EXAMINATION OF TRACK PROBLEM

Event or Condition:	Loose bolts at joints
Cause:	Traffic vibrations
Factors:	Traffic density, speed and wheel loads Condition of track support structure The track walker considered his work acceptable*
Direct Effects:	Wear of joint bars and rails**
Indirect Effects:	Lower ride quality Increased maintenance costs
Normal Practice:	Lubricate bolts and tighten periodically at specified torque Track walker checks and tightens a few loose bolts
Potential Improvement:	Use glue or lock nuts as an add-on to normal practice
Effectiveness:	Leading railroads and transit properties agree that it pays to lubricate and tighten track bolts periodically, and that track degrades rapidly and expensively when bolts are loose
Sub-problem:	Work assignment - Who will do the work? Resources - How will we pay for it?
Actions:	Have the track walker lubricate and tighten bolts periodically Make time available by Reducing quantity of other work Less frequent inspections Fewer repairs or adjustments Less time on fewer/shorter reports Improving track walker's performance Training Improved methods and tools Motivation: recognition, encouragement, competition Form and train special team of two men to lubricate and tighten bolts periodically Hire additional track mechanics Obtain additional funds Reduce other costs Make M/W people available by Reducing quantity of other work Reducing lost time Planning, scheduling and maintaining control Increasing track availability Improving performance Training More & better equipment and power tools Motivation: recognition, encouragement, competition

* The wear between joint bars and rails and looseness of tie plates indicated that many of the bolts had been loose for a long time. Obviously the track walker's work had been accepted by supervisors over that same period of time.

**When the track bolts are loose, movements of the joint bars strain the bolts and sometimes cause them to bend or break. The movements also allow increased deflections at the joint that accelerate the breakdown of the ballast and subbase. If the bolts are not tightened to the required tension, movement will cause the fishing surfaces (contact surfaces) of the joint bars and rails to wear excessively. Eventually, the joint bars will not provide adequate strength even when the bolts are tightened.

TABLE 8. EXAMINATION OF TRACK PROBLEM AREA

1. Clarify problem area.
 - Isolate and describe major problems in the area.
 - Identify any general conditions that relate to the problem area.
2. Examine each major problem
 - Identify causes and factors that affect the problem.
 - Consider its range.
 - Consider its frequency.
 - Identify actions that are known to avoid or reduce the problem.
3. Investigate each major problem to uncover specific sub-problems; identify and describe these specific problems.
4. Review technology to find practices available to correct or reduce the problem/sub-problems.
5. Determine the extent of the problem/sub-problems that cannot be corrected or reduced without research products.
6. Search track and related research programs for tasks that bear on:
 - The major problem.
 - Specific sub-problems.
 - Conditions and other factors related to the major problem.
7. Examine research reports for useful products.
 - Identify practices, materials, tools or equipment that may reduce the problem or its effects.
 - Consider their effects and related factors.
 - Have the products been used? If not, why not?
 - If the products have been used, how effective have they been? How costly? Has their use been accompanied by any new or intensified problems?
8. Check current research for expected products that may correct or reduce the problem.
9. Formulate research tasks to correct or reduce significant problems that are not covered adequately by current technology, past research or research in progress.

that were found were presented in monthly reports and in meetings to representatives of UMTA and TSC, and to the APTA Project Liaison Board. Finally, those potential improvements that had not been culled as a result of earlier discussions were presented at the track seminar in April, 1979. They included items under design, construction and maintenance, as listed and described briefly in Appendix A.

8.2 RELATIVE IMPORTANCE

8.2.1 EVALUATIONS

Relative importance is the first consideration in determining whether or not a research project should be funded to develop a potential improvement. The other considerations are the probability of success for the project and the estimated ratio of its benefits (if successful) to its costs. In most cases, the probabilities of success are very high, as the projects involve the application of known materials and methods that are considered more effective than the materials and methods used in the past for similar work.

The relative importance of potential improvements is determined by the frequency and severity of the problems they would correct, the reduction in the effects of these problems on operations, and the direct costs of the problems. In most cases this information could not be quantified accurately. Accordingly the experience and judgment of the M/W superintendents and their staffs were drawn upon to find the relative importance of the many opportunities for improvement that appear to exist in transit track. These judgments were most valuable when applied to maintenance practices. Design and construction practices were appraised mainly in relation to their effects on maintenance and operations.

In order to obtain a broad review of the potential improvements that were identified during the course of the study, UMTA and TSC included a seminar with workshop sessions in the project. This seminar provided the judgments of experienced consulting engineers, suppliers and transit engineers from other departments as well as the M/W superintendents. All of the opportunities for improvements in transit track design, construction and maintenance that had been clearly identified up to the time of the seminar and had not been culled as a result of discussions with M/W superintendents, were reviewed in the workshops.

The results of the seminar workshop sessions are summarized in Appendix A.

8.2.2 DESIGN AND CONSTRUCTION TASKS

Participants in the Design and Construction Workshop found value in only a few of the items that were listed as potential improvements as noted in Appendix A.2.1.1 and A.2.1.2. Items were not considered if participants felt that current practices were adequate or that designers and contractors, using available information, could decide upon appropriate actions as the situations occurred. The items that were generally considered to be worth some study are listed as tasks 1 through 5 in Table 9, and are evaluated in Appendix B.

Participants in the Design and Construction Workshop also proposed ten items for study. These proposed tasks, listed in Appendix A.2.1.3 and as tasks 7 through 16 in Table 9, were not discussed to any extent during the workshop sessions. Task 7 in Table 9, on weather-related problems, is obviously very important and should be given special attention in view of the problems and high costs encountered last winter when several systems were completely closed at times. Task 13 in Table 9, on the development of a rail-break detection system,

TABLE 9. PROPOSED RESEARCH AND SUPPORT TASKS APPROVED
OR ADDED IN TRANSIT TRACK SEMINAR WORKSHOPS

<u>No.</u>	<u>Work Shop</u>	<u>Task Title</u>
1.	D&C ^α	Guardrail Effectiveness Study
2.	D&C ^α	Protective Filters on Embankments
3.	D&C ^α	Coordination of Design and Maintenance
4.	D&C ^α	Improved Rail for Curves
5.	D&C ^α	Rail Stresses, Elevated Structures
6.	D&C ^α	Continuous Main Rail Frogs
7.	D&C ⁺	Weather Damage Control and Recovery, I
8.	D&C ⁺	Restraining Rail Effectiveness Study
9.	D&C ⁺	Relation of Rail Wear to Support Stiffness
10.	D&C ⁺	Nondestructive Testing of Rail Welds
11.	D&C ⁺	Rail-Wheel Interface Problems
12.	D&C ⁺	Optimum Tie Spacing
13.	D&C ⁺	Rail-Break Detection System
14.	D&C ⁺	Restraining Rail Design and Installation
15.	D&C ⁺	Rail Corrugation and Load Environment
16.	D&C ⁺	Dynamic Forces Concrete Tie Fasteners
17.	M ^α	Industrial Engineering Support
18.	M ^α	Simplified Guidance on Maintenance Management
19.	M ^α	Optimal Standard Inspection and Maintenance Forms
20.	M ^α	Guidelines for Transit Track Systems
21.	M ^α	Track Inspection Techniques, Trackwalkers
22.	M ^α	Training Support
23.	M ^α	Demonstration Projects
24.	M ^α	Ride Quality Recording System
25.	M ^α	Track Availability for Maintenance
26.	M ^α	In-Place Treatment of Wood Ties
27.	M ^α	Practices to Reduce Rail Wear
28.	M ^α	Welded Vs. Bolted Joints in Curves
29.	M ^α	Wheel Grinding Practices
30.	M ^α	Follow-up Studies on Steerable Trucks
31.	M ^α	Corrosion Control
32.	M ^α	Inspection Methods and Tools, Improvement
33.	M ^α	Adjustment of Elevated Track
34.	M ^α	Maintenance Hand Tools, Improvement
35.	M ⁺	Processes for Welding Rail in Track
36.	M ⁺	Switch Maintenance, Switch Point and Frog Rehabilitation
37.	M ⁺	Electric Switch Heater Installation on Switch Points and Guard Rails
38.	M ⁺	Favorable Maintenance Practices in Limited Use

Notes: D&C - Track Design and Construction Workshop
M - Track Maintenance Workshop
α - Task presented as a result of the project
discussions and approved in workshop
+ - Task added in workshop

is also considered very important because of the safety factors involved. An analysis of this task is included in Appendix B.

Tasks 8 and 14 in Table 9 (one on the effectiveness of restraining rail and one on its design and installation practices) are covered by a study on restraining rails that was recently initiated, and by a proposed study of current practices for the reduction of the wear of rails on curves.

Task 10 in Table 9, on the non-destructive testing of welds, is being studied by many different laboratories and universities mostly in relation to large structures and equipment. However field applications of the research (other than the ultrasonic testing now in wide use) are difficult to foresee. Good results with ultrasonic testing are claimed by several railroads and transit properties. The quality of the results depends mainly on the training, skill, imagination and diligence of the inspector. For best results all extrusions of weld material have to be removed from the rail and all surfaces ground clean, since the extrusions would mask defects. In addition a surface effects probe should be used to find surface cracks that will not be detected by the probe used to detect internal flaws.

The five other tasks (numbers 9, 11, 12, 15 and 16 in Table 9) concern the collection and development of basic information on wear and load transfer processes, but they are not focused on conditions that are peculiar to transit properties. They are considered appropriate for railroad research, as the potential benefits would be much higher for railroads than for transit systems in relation to the high cost and uncertainty of obtaining usable products from the research.

Later review of the seminar discussions and current practices indicated needs for criteria to supplement AREA guidance for concrete ties, subballast and soil protection, direct fixation

fasteners, tie plates in relation to noise damping, curvature, superelevation, and the effects of elevated structure characteristics on ride quality. Flange lubrication is an item that especially requires definitive criteria because of the excessive wear and high noise levels often associated with the sharp curves that are necessary in some sections of transit track.

8.2.3 MAINTENANCE TASKS

Nine suggested opportunities for improvements with current technology were reviewed by participants in the Maintenance Workshop as noted in Appendix A.2.2.1, and seven were approved. The seven are listed as tasks 17 through 23 in Table 9. Of these tasks, 18 and 19 are considered to be included in 17, the tasks for industrial engineering support. Task 20 on guidelines and recommended practices should be evaluated after information becomes available from studies on related subjects that are underway. Task 23, on the support of demonstration projects, is already being funded on a case-to-case basis. The remaining tasks, numbers 21 and 22 in Table 9, have been analyzed for costs and benefits along with task 17 shown in Appendix B.

Task 22, on training support, was envisioned as a Phase I effort to define the scope, value and cost of a training support program. The program should enhance the track training now being conducted by some of the transit properties, extend the benefits of adequate training to all properties, and assist them to take full advantage of available training resources.

Eleven tasks proposed for research or investigation were approved during the maintenance review as noted in Appendix A.2.2.2. They are listed as tasks 24 through 34 in Table 9, and all but task 30 have been analyzed as shown in Appendix B.

Task 30 is being handled as a project separate from the track research program.

Three candidate tasks proposed by participants in the Track Maintenance Workshop are listed as tasks 35 through 37 in Table 9. Task 35, research on rail welding, is considered very important, but its scope and potential are difficult to determine without an extensive investigation of the relative merits of the commercial welding systems that are now available, which would be feasible under task 17. Flash butt welding of rail (using a Russian welding head) is preferred by several railroads because of the reliability of the welds and because no additional material has to be bought. Excellent results with thermite welding are claimed by the Toronto Transit Commission. The Commission has trained its own technicians to inspect rails and welds with portable ultrasonic devices. Flawed rail ends are cut off before welding and welds with slag inclusions are cut out and replaced. One of the European transit systems claims excellent results with an electric arc welding system, clamping large copper heat sinks to the rail and finishing with a special electrode that gives a hard, tough rail surface. Good information on welding techniques used effectively by railroads to rebuild frogs and switch points and repair surface damage in rails is available from manufacturers.

Information on effective techniques for switch maintenance and rehabilitation of switch points and frogs (task 36) is available in manufacturers' literature and in trade magazines. Review of this information against the practices of transit systems that have been doing such work could be included in the industrial engineering support task, number 17. Information and practices for installation of electric switch heaters on switch points and guardrails (task 37) could be reviewed under task 17, and needs for intensive investigation or research could be clarified at that time.

Thirty-five favorable maintenance practices that had been identified as being in limited use were reviewed and approved with a few qualifications as noted in Appendix A.2.2.4. They are grouped as task 38 in Table 9. Task 17 for industrial engineering support is considered to be the best vehicle for the further evaluation of these favorable practices and for encouraging their use throughout the transit industry. Because of this and other factors discussed in Section 8.3.5, the industrial engineering support should be provided by a highly qualified team and should be tailored to the individual needs of the separate transit properties.

Two additional tasks of potential value were identified during review of notes on the seminar and consideration of current maintenance practices: improvements in power tools for track maintenance and improvements to maintenance equipment.

The task for industrial engineering support is considered to be of such large potential value that further discussion is warranted.

Transit track maintenance was observed to have produced results that are generally of much higher quality than is common in other industries. Productivity tends to be lower, however, since clearances and dense traffic impede the use of equipment and interrupt work crews. In addition, the relatively small quantities of work performed often are not conducive to the development and retention of the skill levels needed for high quality work. New technology is available to help in this situation. One of the great advances in engineering technology in the last 30 years has been the advance in the planning and control (management) of maintenance engineering. When implemented, it enables mechanics and supervisors to do their best and not be hampered by delays, inadequate information, and inadequate tools and materials. These advances have been

an outgrowth of operations research studies aimed at optimizing the use of military resources and industrial engineering studies aimed at improving the profitability and quality of manufactured products. Guidance is available in handbooks^{35,36} but is difficult to apply to situations for which it was not specifically prepared. This is especially true when M/W superintendents are kept very busy by routine demands on their time and by irregularities that occur frequently in track maintenance and demand special attention.

In the situation, centralized industrial engineering support can provide very valuable assistance. It should continue over a period of time long enough for the specialists to gain a full understanding of transit conditions and for them to obtain industry-wide acceptance of improvements in the quality and productivity of track maintenance. The advantage of various favorable practices can best be seen by comparison, and true comparisons cannot be made if efforts are restricted to a local level. At the local levels, there are often strong incentives against change and strong incentives for managers and supervisors to allow local preferences to dominate decisions that might otherwise introduce changes which could improve track maintenance.

8.3 COST ANALYSES

8.3.1 LIFE CYCLE COSTS

The life cycle costs used in the analyses are the total costs of ownership of the subsystem or component that is under consideration. These costs include:

³⁵ Lewis, B. T. and Marron, J. P., Editors, Facilities and Plant Engineering Handbook, McGraw Hill 1973.

³⁶ Feldman, E.B., Industrial Housekeeping, Its Technology and Technique, McMillan, 1963.

- Research and development costs
- Planning and design costs
- Purchase costs, including spares and necessary tools
- Initial costs of such items as transportation, installation, down time or slow orders during installation, removal and disposal of items replaced, revision of record drawings and track plans, and any special training.
- Operating costs and operating overhead
- Maintenance costs and maintenance overhead

A component or subsystem may last only a fraction of the life cycle of the track system, and its total life cycle costs will then include several complete replacements plus the removal and disposal of the items replaced. In many cases it is not feasible to identify the operations and maintenance (O&M) costs associated with a track component except as an appropriate share of the O&M costs of the entire track system. When a more durable component is considered, no difference may be seen in O&M costs except for replacement costs during the track system life cycle.

8.3.2 LIFE CYCLE

Review of the transit track usage, projected density of use, and growth of urban areas indicate a life cycle of more than 50 years for transit systems except in the cases of lines for which replacements are already planned. Planning a system life cycle longer than 50 years is invalidated by high interest rates and uncertainty factors that increase with time.

With an interest rate of 10%, a savings to be made in 50 years (such as one to be obtained by providing a more durable track component with an extended useful life) has a present value of less than 1% of the future savings. Conversely, the uncertainty factor that must be considered in all planning

increases rapidly as plans are projected farther and farther into the future. It is doubtful that many conditions can be predicted with an accuracy better than $\pm 20\%$ for periods of more than 5 years from now. Accordingly, planning for the use of a facility beyond 50 years in the future would not be meaningful.

Track research projects should extend the useful life of track components and/or make their cyclical replacement easier and cheaper during an overall life cycle of 50 years; or they should reduce the cost of track maintenance by increasing productivity and/or quality during the 50-year life cycle.

8.3.3 CONDITIONS

Tangent track has lasted as long as 50 years in a few cases with no major replacement of components. Current interest rates are above 10%. The cost of servicing the government debt is over 10%. Although lower interest is paid on tax-sheltered bonds, there are hidden costs to the government in connection with such bonds. High interest rates tend to favor the increase of routine maintenance and frequent replacement of cheap components in order to avoid or defer additional investment. On the other hand, lower interest rates tend to favor increases in capital investments and expenditures which will improve maintenance productivity/quality, so as to reduce annual maintenance costs.

Actions to increase the overall efficiency of track maintenance are generally favorable at any level of interest. The present value of future savings to be obtained by improving maintenance is greater at low interest than it would be at high interest.

8.3.4 ASSUMPTIONS

The changes made to improve a track component or its maintenance as a result of research and tests will not adversely affect other track maintenance or operating costs.

Costs (of labor, materials and equipment) and income will tend to rise at the same rate. This broad assumption permits the omission of the complicated effects of inflation from the calculations and makes comparisons easier. Energy costs are a major exception to this generalization; but, if they continue to rise at above average rates, the effect will tend to increase the values of savings in work and materials.

Simplified analyses with interest compounded annually are adequate, since costs used are broad, nationwide approximations rather than the precise cost estimates that would be developed in planning a project at a specific location and definite time. This simplification includes the assumption that cash flow will be uniform year-end cash flow each year.

8.3.5 TASKS

The cost analyses of individual tasks that are recommended for funding are provided in Appendix B. Review of these analyses shows that, for an improvement to be beneficial, it would have to increase track safety and/or ride quality, reduce construction costs or reduce maintenance costs. (There were no indications that any of the proposed tasks could directly reduce operating costs).

Potential improvements in track safety and ride quality (including noise reduction) cannot be quantified easily, but they are considered very important to the overall performance and financial strength of transit properties because of their close relation to passenger satisfaction and public support.

Many informal comments to this effect were made by representatives of the transit industry during discussions of the current project and in reply to questions presented at the Transit Track Seminar held in New York City, April 1979.

Reductions in construction cost come at the beginning of a track's life cycle. They have full value and amount to reductions in investment, as they do not have to be discounted to present value in the way that estimated future savings must be discounted. Thus they are particularly significant when interest rates are high. In addition, some reductions in construction costs can be expected to repeat when similar construction is performed in the future. Unfortunately few opportunities were found during the project for reductions in construction costs. While these opportunities certainly exist, finding and defining them would take intensive efforts during the course of design and construction of a track system, such as those made in a value engineering study.

Reductions in maintenance costs obtained by an improved track component or improved methods are usually repeated year after year throughout the life cycle of the track, and the present value of the repetitive savings is much higher than the initial savings at the time the change is made. An increase in track durability is equivalent to a decrease in maintenance costs; but the effects will usually be deferred for a long time, and their present value will be very low because of current high interest rates. High interest rates are not expected to decrease in the foreseeable future, unless a long recession occurs, because the additional tax advantages recently given to speculative investments will tend to drive interest rates higher as similar incentives have already done in other countries.

Because of the high, repetitive cost of track maintenance, estimated at more than \$60 million per year throughout the 50-year life cycle of the track, the accumulated savings or cost reductions that result from even a small maintenance improvement will be very large. For this reason, the highest value task was found to be industrial engineering support, continued over a period of at least five years. It will facilitate the wide use of the 35 favorable maintenance practices listed in Appendix A.2.2.4 and other available technology that will be beneficial to the transit properties. The full benefits of the industrial engineering support task will not be realized until after five years of continuing effort; but, after the first six months, the stream of benefits should be continuous. The total was estimated to be a continuing improvement of 9% in the effectiveness of track maintenance which has a present value over \$30 million when discounted at 10% interest.

This high value task will require careful investigation of local conditions and the modification of favorable practices to suit them, follow-through actions to give firm support to the trial applications of new methods, further adjustments, follow-up visits, and validation of improvements. It can be achieved only by an industrial engineering team that increases its knowledge and skill as the task progresses, by comparing the cost-effectiveness of track maintenance practices in several transit systems. Providing industrial engineer staffs at each of the transit properties would not be as effective as providing continuing central support, because the elements of consistency and comparison would be lost.

The 35 favorable maintenance practices listed in Appendix A.2.2.4 as in limited use and several others were not analyzed separately but were considered in the analysis of the

industrial engineering support task. Each of the 35 favorable quality of track maintenance at different properties, but each would contribute to the estimated overall improvement of 9% in maintenance effectiveness.

The most favorable task that was identified in the design and construction areas was the investigation of stresses in CWR on elevated structures. It has a high estimated value because it would permit the conversion of bolted rail to CWR on open-deck elevated structures and thus lead to repetitive savings in future track maintenance. The design-related task next in value (a study of communications between planners, designers, contractors and maintenance engineers) would affect the construction of new track but would have a present value of about \$700,000 mainly because of estimated savings in future track maintenance.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

9.1.1 TASK IMPORTANCE

The reviews by members of the Design and Construction Workshop and the Maintenance Workshop provided very effective screening of the potential research and support tasks recorded in Appendix A. The selection of tasks for analysis should be based primarily on these reviews. The tasks that were approved or added in the workshop are listed and numbered in Table 9, page 107.

Several potential improvements suggested in design and construction were agreed to be of little value during the review. These items should not be considered further. They are discussed in Appendix A.2.1.1 and A.2.1.2, but are not listed as proposed tasks in Table 9, page 107.

Five of the six candidate tasks that were found to be worth further study during the design and construction review (tasks 1 through 5 in Table 9 and Appendix A.2.1.1 and A.2.1.2), should be considered for funding. Task 6, a study of continuous-main-rail frogs, should be deferred until results are available from a study by MBTA that is now underway.

Two of the ten additional tasks suggested by members of the Design and Construction Workshop (Appendix A.2.3.1, tasks 7 through 16 in Table 9) should be considered for funding. These are: task 7, a study of weather-related problems, and task 13, development of a rail-break detection system. The other tasks (8, 9, 10, 11, 12, 14, 15 and 16) should be dropped from further consideration at this time. As discussed in Section 8.2.2, they are included in other tasks, or involve research that is generally funded by another agency, or cover information that is already available.

Seven tasks (17 through 23 in Table 9) proposed for improvements with current technology, were approved in the Maintenance Workshop, as noted in Appendix A.2.2.1. Three of these should be considered for funding: task 17, Industrial Engineering Support; task 21, Track Inspection Techniques; and task 22, Training Support. The industrial engineering support task should be handled on an individual property basis, as recommended during the review; but it should be handled by one, highly skilled industrial engineering team that will not miss any of the experience to be gained at the different properties.

Action should be deferred on one of the approved tasks, number 20 in Table 9, Guidelines for Transit Track Systems, until information is available from other studies that are underway on related subjects.

Two of the approved tasks, number 18 Guidance on Maintenance Management, and number 19, Optional Standard Inspection and Maintenance Report Forms, should be included in task 17, Industrial Engineering Support. The remaining approved task, number 23, Support of Demonstration Projects, is already being handled on a case-to-case basis.

Ten proposed tasks that require research or investigation were approved and assigned priorities during the maintenance reviews, as noted in Appendix A.2.2.2. These tasks (numbers 24 through 29 and 31 through 34) should be considered for funding.

Three tasks were proposed by the members of the Maintenance Workshop, as listed under Appendix A.2.2.3. These are tasks 35, 36 and 37 for rail welding processes, switch maintenance and rehabilitation, and switch heater installation.

Much technology has been developed concerning each of these subjects as discussed briefly in Section 8.2.3. Information on these three subjects should be reviewed and made available to the transit properties under task 17 for industrial engineering support, before further studies are planned.

Thirty-five favorable maintenance practices that are in very limited use were discussed and approved during the maintenance review with some qualifying comments as noted in Appendix A.2.2.4. Wider use of these favorable practices should be encouraged under task 17 for industrial engineering support.

9.1.2 TASK VALUE

The data used in the analyses of the candidate tasks in Appendix B are approximate but adequate for sound decisions on the relative cost-effectiveness of options that are available for the improvement of transit track. The data generally are well within the range of available predictions of future conditions that will affect costs and benefits. Conditions in the mid-term future (5 to 15 years from now) will have large impacts on the estimated benefits from most of the tasks that could be implemented, and predictions of conditions in that period cannot be expected to be better than $\pm 20\%$.

The analyses in Appendix B are considered valid, and the candidate tasks should be ranked according to their relative benefits over the life cycle of the track, discounted to their present value. Consideration should also be given to their relative importance (urgency) as discussed in paragraph 9.1.1 and Appendix A, and to the sequence and level of effort at which the tasks can be accomplished most effectively.

9.1.3 PROGRAM IMPLEMENTATION PLAN

No tasks were found that could produce immediate results, although a considerable volume of technology was found

available in the U.S. and overseas that could benefit transit track. The most effective task in this respect would be number 17, to provide highly skilled industrial engineering support. This would assist M/W superintendents (already very busy with regular maintenance and irregular problems that occur frequently) to evaluate and adapt favorable technology to the special needs of their transit systems. Phase I of this task is shown as the first item in Table 10, Transit Track R&D Task Estimates. It should begin to produce some beneficial results within six months and at an increasing rate thereafter, until it has drained the pool of technological improvements that are currently available.

Several other tasks that were discussed should begin to produce beneficial results within a year of the time they are started. Most of the tasks will take longer periods to produce results as indicated in Table 10 which lists all of the tasks that were evaluated. Obtaining results from many research and support tasks in the brief periods indicated in Table 10 is very unusual. If the tasks are pursued vigorously, it will occur in this case because of all the tasks build on the use of proven technology and the application of research products that have already been used effectively in other work.

Two tasks have been omitted from Table 10 because information was not available to support estimates of their costs or analysis of their probable benefits. These tasks are Training Support, Phase II, and Weather Damage, Control and Recovery, Phase II.

Task 25 on track availability for maintenance was given first priority, instead of priority 3 as recommended in the workshop, because of the estimated high value of its results.

TABLE 10. TRANSIT TRACK R&D TASK ESTIMATES*

<u>Category</u>	<u>Task</u>	<u>Priorities & Costs</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
	Interim--Results within one year			
MS**	Industrial Engineering Support, Phase I	250		
MS	Track Inspection Methods, Trackwalkers		70	
T **	Track Availability for Maintennace	100		
MS	Protective Filter on Embankments			25
T	Wheel Grinding Practices			60
DS**	Guardrail Effectiveness		80	
MS	Training Support, Phase I		30	
MS	Weather Damage, Control and Recovery, Phase I	30		
	Short Term--Results in Approximately Two Years			
MS	Industrial Engineering Support, Phase II	250		
T	Coordination of Design and Maintenance	130		
T	Ride Quality Recording System	90		
MS	In-Place Treatment of Wood Ties		150	
DS	Rail Stresses, Elevated Structures		150	
DS	Welded Joints vs. Bolted Joints in Curves		90	
MS	Corrosion Control		110	
MS	Rail Break Detection Syste, Phase I	100		
	Intermediate--Results in 2 to 5 years			
MS	Industrial Engineering Support, Phase III	250		
MS	Industrial Engineering Support, Phase IV		250	
DS	Practices to Reduce Rail Wear	120		
T	Inspection Methods & Tools, Improvement		120	
T	Maintenance Hand Tools, Improvement			120
MS	Rail Break Detection System, Phase II	275		
DS	Adjustment of Elevated Track			180
DS	Improved Rail for Curves			280
	Long Term--Results after 5 years			
MS	Industrial Engineering Support, Phase V	250		
DS	Criteria to Supplement AREA Specifications		170	
T	Maintenance, Power Tool Improvement			120
T	Maintenance, Equipment Improvement			120
	TOTAL PROGRAM	1845	1220	905

* Time estimated from start of task to initial results.
Costs estimated in thousands of 1979 dollars.

**DS-design standards, MS-maintenance standards, T-technology

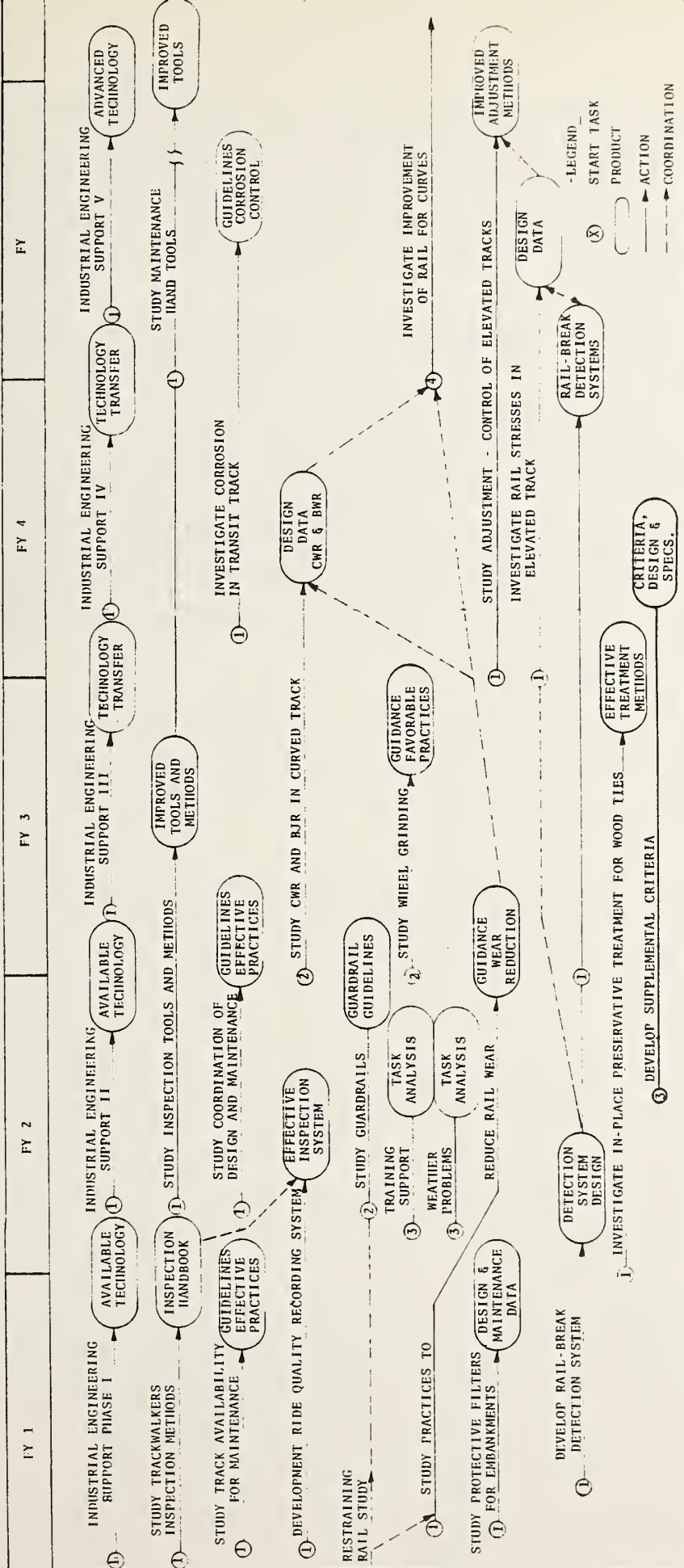
Some of the tasks listed in Table 10 overlap the categories indicated for them: design standards, maintenance standards, and technology.

9.2 RECOMMENDATIONS

The proposed sequence and relation of the tasks recommended for funding are shown in Fig. 37. It is recommended that the 19 research and support tasks and task phases marked ① in Fig. 37 be funded in the fiscal years indicated on the figure. This recommendation is based on the study of track conditions, requirements and available technology as discussed in other sections of this report, and the comments and recommendations of representatives of the transit industry as summarized in Appendix A. The 19 tasks and task phases have estimated benefits that far exceed their estimated costs as analyzed in Appendix B. They are task numbers 2, 3, 5, 13, 17, 21, 24, 25, 26, 27, 31, 32, 33 and 34 in Table 9, page 107. Task 13, Rail-Break Detection System, has two phases and task 17, Industrial Engineering Support, has five phases.

The funding of three tasks whose benefits could not be estimated at this time is also recommended because of the importance of these tasks for track safety. These three tasks (numbers 1, 28 and 29 in Table 9) are marked ② in Fig. 37.

Three other tasks whose benefits have not been estimated should also be funded and are marked ③ in Fig. 37. Two of them (numbers 7 and 22 in Table 9) are preliminary to tasks that can be expected to produce substantial benefits. The third task, Criteria to Supplement AREA Specifications, is not listed in Table 9 as it was identified after the Transit Track Seminar. It is considered important, as it will produce simple criteria for the use of information developed under several other tasks and collected from other sources.



NOTES: Tasks marked ①, ② or ③ are recommended for funding as discussed on page 124.
 The task marked ④ is recommended for reconsideration in 1981 as changes in conditions may improve its estimated benefit cost ratio.

Fig. 37

Sequence and Relation of Tasks in Transit Track R&D Program Implementation Plan

Task number 4, on the investigation of improved rail for curves, marked ④ on Fig. 37, has an estimated benefit less than its estimated cost. This task should be reconsidered in 1981, as developments in metallurgy and tribology may increase its potential value.

Two follow-on tasks, identified after the Transit Track Seminar and not listed in Table 9, have not been analyzed for benefits and have not been entered on Fig. 37. These tasks are the improvement of power tools and improvement of equipment for track maintenance. It is recommended that these tasks be considered for funding in a later period, if analyses (using data from preceding tasks 32 and 34 on improved hand tools for track inspection and maintenance) show that they will have high value benefits.

Task 6, on continuous-mainrail frogs, omitted from Fig. 37, should be considered when information becomes available from a related study by MBTA.

Task 20, on guidelines and recommended practices for transit track systems, not included in Fig. 37, should be considered when data becomes available from related studies by APTA that are now underway.

Task 35 on track welding, task 36 on switch maintenance and rehabilitation, and task 37 on switch heater installation, all omitted from Fig. 37, should be reconsidered after the information available on these subjects has been collected in the course of the industrial engineering support task.

Many of the tasks recommended are relatively small in scope and effort, and the combination of such tasks into larger projects should be considered. This should have the effect

of reducing administrative and travel costs in relation to the cost of productive work and help ensure high quality results.

Suggested combinations of tasks are as follows:

Track Availability for Maintenance
Guardrail Effectiveness

Track Inspection Methods, Trackwalkers
Ride Quality Recording System
Inspection Methods and Tools, Improvement

Wheel Grinding Practices
Welded Joints versus Bolted Joints in Curves
Practices to Reduce Rail Wear

Training Support, Phase I
Weather Damage, Control and Recovery, Phase I
Coordination of Design and Maintenance

In-Place Treatment of Wood Ties
Rail Break Detection System, Phase I

Rail Stresses, Elevated Structures
Adjustment of Elevated Track

Corrosion Control
Maintenance Hand Tools, Improvement

The program plan should be reviewed within three years, since changing conditions will reveal additional opportunities for improvements and will affect the values of potential benefits from tasks that were considered under the current study.

APPENDIX A

SUMMARY OF TRANSIT TRACK SYSTEMS SEMINAR NEW YORK CITY 25 APRIL 1979

A.1 PRESENTATIONS

The project status was reported by the principal investigator. He discussed the work briefly and presented tentative findings and recommendations for review in the seminar workshop. One set of tentative findings and recommendations covered track design and construction, while the second covered track maintenance, including inspection. Each set of conclusions and recommendations included potential improvements available from state-of-the-art technology, and improvements considered attainable through favorable research tasks. Participants in the seminar workshops were generally familiar with the tentative conclusions and recommendations as a result of discussions at their respective transit properties, their work on the Project Liaison Board and information that had been forwarded to them in preparation for the seminar.

A review of European technology was presented by J.A. Woods of London Transport International (LTI), who briefly discussed differences in track practices and efforts to increase track durability and reduce costs. The discussion was primarily concerned with the transit properties of four cities: London, Paris, Hamburg and Stockholm.

London Transport (LT) uses bull-head rail which is rolled with two symmetrical heads, so that it can be turned over and kept in use after the top head had been worn beyond specified limits. Unfortunately the "chairs" that support the rail wear grooves into the bottom head, so that it is not suitable for a running surface. However the bull-head rail has other advantages. Its narrow width permits the installation of check (restraining) rails without having to crop off a

bottom flange, and its depth places car wheels $3/4$ inch lower than T-rail would (with the same size head for wear resistance) so as to give better vertical clearance. Bull-head rail is becoming increasingly costly since LT is now the only user, and LT plans to change gradually to T-rail, as the bull-head rail wears beyond use.

Continuous welded rail (CWR) is considered the most important development of the last 30 years in helping to reduce track costs. LT welds 60-foot rails into 300-foot lengths, the largest that can be handled in its yards, and connects the welded rails with machined joint bars and high strength bolts with no field welding. LT had had few weld failures, and only one bolted joint failure in 30 years. At a failed weld, temporary joint bars are clamped on the rail promptly and the joint is rewelded later, as soon as the work can be done conveniently. While bolted joints are convenient for maintenance work, LT is interested in the practice that has developed on the Continent of welding all joints, so that the rail is continuous through turnouts and crossings. In track systems on the Continent, lengths of CWR are connected with thermite welds except in Stockholm where electric arc welds are used. From 0 to 30 weld failures are expected each year on different systems.

LT engineers are interested in fasteners that will provide longitudinal restraint, so that rail anchors will not be needed when they change to CWR T-rail. The elastic spikes that they have tried do not hold the rail down tightly. They have studied many fasteners developed in recent years in order to obtain fasteners with good torsional strength that will help resist track buckling forces, as well as adequate longitudinal and lateral restraint. They have avoided fasteners with bolts and other threaded connectors that need repetitive oiling, tightening and careful inspection. Fastener clips that are driven at right angles to the rails cannot be used,

because the working space on LT track is confined by a return power rail installed between the running rails, as well as a contact rail on one side. LT engineers have decided that the Pandrol clip best suits their needs.

Check (restraining) rails are used on sharp curves of the LT system and are required by law on curves of 660-foot radius or less. LT engineers are very interested in the elimination of check rails by British Rail and other systems, except for guard rails at frogs and crossings. Many engineers consider check rails unnecessary where all cars have their wheels mounted in trucks.

Recently LT has developed a truck with a motor on each axle and the pintle in the center to replace the old truck with a heavy motor on one axle and an offset pin. This new truck has reduced noise and wheel wear and is expected to reduce wear of the rails. Rheostatic braking has been introduced with good results, including a reduction in the oily dust found on track and an increase in the interval between wheel grindings from 50,000 to 150,000 miles. For the Hamburg system, the wheel grinding interval was said to have been increased from 155,000 to 370,000 miles, and approval is being sought to lengthen it to 435,000 miles.

LT has been investigating wheel-rail noise and is interested in damping the ringing of the rails. Bedding the rails in sand will do it, but the sand interferes greatly with maintenance work.

Studies by the British Railways Research Group have shown that a total depth of almost five feet of granular material and ballast is needed on poor soils to avoid increasing deformation of the subsoil and degradation of the track under traffic. This finding is supported by the experience of transit systems on the Continent. They have been able to reduce track resurfacing to approximately once in ten years by placing and compacting deep layers of ballast and using tie spacings of 23 to 27 inches.

Stockholm, using a tie spacing of 31 inches on 20 inches of compacted ballast on very good subsoils, has also reduced resurfacing to about once in ten years. LT, using a minimum of 10 inches of ballast under ties and a tie spacing of 31 inches, resurfaces once every two years. Concrete ties tested on LT were successful when installed at a spacing of 31 inches but failed at a spacing of 36 inches, possibly because the tie spacing, car characteristics and speed resulted in resonant vertical forces.

A.2 WORKSHOPS

The seminar participants separated into two groups to review and discuss the tentative findings and recommendations developed under the contract and to contribute the views of the transit industry for the final conclusions and recommendations.

A.2.1 DESIGN CONSTRUCTION WORKSHOP

Chairman: Erland A. Tillman, Associate Vice President
Daniel, Mann, Johnson & Mendenhall

Members:

William Anido Principal Civil Engineer Metropolitan Dade County Transportation Adm.	William L. Barnes Project Manager Chicago Urban Transportation District
Kenneth J. Belovarac Assistant Project Manager Track Improvement Program Mass. Bay Transp. Authority	John Bledsoe Research Engineer Underground Technology Development Corp.
Stanley J. Carroll Chief, Transit Civil Section Philadelphia Department of Public Property	Homer Chen Design Engineer Washington Metropolitan Area Transit Authority
Frank Cihak Mgr., Technical Programs American Public Transit Assn.	Robert Clemons Project Manager Bechtel, Inc.
Thomas F. Connolly, Jr. Resident Engineer Mass. Bay Transit Authority	Robert J. Conrigue Kaiser Transit Group Trackwork Project Engineer

William J. Custer, Jr.
Project Manager
Kaiser Engineers, Inc.

Ronald H. Dunn
Parsons Brinckerhoff Centec, Inc.
Enterprise Center

Robert D. Garrison
Manager, Construction Mgmt.
Transit Systems Development

Theodore C. Hardy, Director
Planning, Construction & Develop.
Allegheny County Port Authority

Martin C. Hearne
Canadair Services, Ltd.

Shen-Yi Hu
Delon, Hampton & Associates

William Jordan
ENSCO, Inc.

Martin Kornspan
New York City Transit Authority

Michael McInnis
Resident Engineer
Mass. Bay Transit Authority

A.D. Park, General Superintendent
Engineering Department
Toronto Transit Commission

Robert H. Prause
Manager, Applied Dynamics
Batelle Laboratories

T. James Rudd, Division Manager
Transportation & Instrumentation
Sciences Division
ENSCO, Inc.

Donald Schoff
Chief Trackwork Engineer
Daniel, Mann, Johnson &
Mendenhall/Kaiser Engineers

Harry Tietjen, Project Manager
Maintenance of Way
Metropolitan Atlanta
Rapid Transit Authority

Francis H. T. Wagner
DeLeuw, Cather & Company

George P. Wilson, President
Wilson, Ihrig & Associates, Inc.

A.2.1.1 Potential Opportunities for Improvements with Current Technology

These items are listed in the order in which they were discussed.

1. Conduct value engineering reviews of all designs as an effort funded separately from the design contracts.

The members of the committee were very divided on this topic, although a majority opposed it. Those in favor of the topic felt that it might supply useful information for future construction of large properties. They also suggested that value engineering might give a new perspective to general engineering consultants whose methods have not changed for some years.

Members who were against the topic stated that value engineering might not be useful for already existing systems using pre-determined design techniques and components. They felt that

the practicability of value engineering was not justified given the financial, political and scheduling limitations imposed upon designers. Still others noted that design engineers are best qualified to do value engineering, and that they are already doing it. Finally, members were not sure that value engineering should be funded separately. They suggested that transit properties supplement value engineering with their own efforts.

2. Offer incentives to construction contractors to obtain the full benefit of their ingenuity and local knowledge by sharing with them the savings that are obtained from any of their recommendations that are accepted.

Committee members were in agreement on this idea which is being used by a number of properties that consider it very valuable. It was agreed that very few design changes were made but that the savings came about through different construction methods and that this item could be considered value engineering for contractors. MARTA was said to be getting good results with it in construction.

One discussion centered around performance specifications. If **performance** specifications are drawn up initially for the construction job, then the contractor has several options available to do the construction work which will meet the specifications. Performance specifications were felt to be particularly useful in choosing fasteners. An example was cited in which lighter fasteners might be chosen to meet performance specifications. Another example given was the shield used at WMATA. Members basically agreed that this is a good idea which can protect them from a poor contracting performance, and that those properties currently practicing this idea find it valuable.

3. Install guardrails at the ends of all station platforms, through-girder bridges and other obstructions.

The committee was very divided on the use of guardrails. There are many pros and cons throughout the industry. Some members felt that money is saved through the use of guardrails since accidents are reduced. Others noted that backup research is needed, because the importance of the topic demands additional study. It was generally thought that research would be interesting but may not be valuable because most designers have preconceived ideas on the use of guardrails. Of the new designs, BART and MARTA do not have guardrails. UMATA has guardrails but only because of legal requirements.

4. Reinforce the edges of station platforms so they will act without failure as smooth guardrails and reduce car damage in cases of derailments.

It was agreed that negligible damage to cars occurs in stations, and therefore no improvements are necessary. One member observed that the population of accidents associated with derailments in stations is so small that it does not warrant study.

5. Install guardrails at the ends of low obstructions built close to or between the rails, so that the obstructions cannot knock the trucks from under a car that may derail at high speed.

It was agreed that this is site specific and that designers should realize this and take needed action.

6. Consider installing combined safety barriers - noise deflectors on elevated track structures in quiet zones.

The committee agreed that this suggestion would be very expensive and not cost effective. A very expensive example in Sao Paulo was cited. Another comment was that barriers would be ineffective in stopping vehicles just as guardrails are. There was some discussion of attenuating noise versus reducing the generation of noise, with no conclusion reached.

7. Eliminate suspended joints in all but ballasted track in order to avoid the extra stress concentrations and wear that occur because of the discontinuities at both welded and bolted joints.

One member commented that this is a good idea but presents very difficult logistics problems. Another notes that it would be very difficult to provide direct support for an insulated joint. In general the committee felt that this would be extremely difficult to do and not cost effective considering the light loads of transit trains on the track.

8. Reduce track construction tolerances to limits that can be achieved by contractors and measured by inspectors.

The committee totally disagreed with the reduction of tolerances. They felt strongly that construction limits should not be lowered, and that present tolerances should be met by competent contractors.

9. Install crushed stone to the top of the rail web on slab track in order to reduce noise in stations and quiet zones, by damping the rails to reduce their efficiency as noise generators and by impeding the reflections of noise from the concrete slab.

It was noted that this idea has been effective on the Toronto system, although ballast gets clogged with dirt. One member mentioned that crushed stone is satisfactory for the purpose, but its cleaning is difficult; and the stones must be small in order to absorb sound effectively. The committee agreed that the suggestion would not be effective, since it would cause too many problems in electrical circuits, inspection cleaning and other maintenance.

10. Design accurate, adjustable, templates so that grout pads can be placed for rails routinely within acceptable tolerances.
11. Prepare detailed guidance for the installation of rails on concrete slabs to accurate line and grade without drilling, shimming or using large quantities of epoxy.

The committee felt both items 10 and 11 to be the responsibility of the contractors, and that the contractors should be responsible for developing the techniques needed to install the rails properly.

12. Standardize on the smallest available tie plates and fasteners that will distribute wheel loads within the bearing capacities of ties and slabs; and eliminate the large, costly plates and fasteners designed for heavy railroad wheel loads.

It was noted that most track is designed around what is readily available and that developing small tie plates and fasteners may not reduce costs. One member noted that availability is a problem. Another mentioned that noise is a problem in direct fixation if small plates are used, and another commented on the Union Pacific tests of tie plates. The committee concluded that there are no real problems in using over-strength fasteners developed for railroads, particularly when they cost less than special fasteners.

13. Provide at least two inches of filter sand with a gradation designed to prevent the movement of fines between clay or silty clay soils and subballasts of available granular material.

The committee considered this suggestion applicable in certain cases such as poor subgrade conditions, but it should not be used everywhere as a matter of policy. An interest was expressed in filter fabrics, and the committee agreed that information on their use would be valuable.

14. Strengthen ballasted track with bolted joints by providing special large ties under the joints.

It was agreed that this is not warranted for transit loadings, and that the cost would not be justified.

A.2.1.2 Potential Opportunities for Improvements Requiring Research

1. Investigate factors in the effective association of designers with construction and maintenance engineers, and develop recommendations for actions that will enhance the transfer of information and ideas. The purpose is to assist designers to avoid features that are hard to build and maintain, and to include items that will facilitate maintenance. It applies to structures and equipment close to the track or related to it as well as the track itself.

The committee members agreed that improvements in communication would be valuable in many cases, but they were uncertain as to how an investigation should be conducted. Members commented on the effectiveness of interdepartmental coordination at the properties. At NYCTA for example, designs are always submitted to maintenance-of-way. In fact, work that the contractor does for the designer has to be signed off by the maintenance-of-way manager. In Boston, the contract designer prepares a brief for the maintenance-of-way people. If there are items that need investigation, the designer or consultant works directly with the office overseeing the project. At TTC designers work hand-in-glove with maintenance and on the DMJM staff there are contractor personnel among the designers.

Problem areas were also noted during the discussion. The interaction between departments is handicapped by personalities and organizational constraints. One member observed that there is not only a lack of communication between designers and engineers, but there is also a difference in their priorities. Maintenance people often want more in the design than is affordable, and designers sometimes cut corners to reduce costs which can make maintenance difficult. Unique problems are also encountered in new systems. A representative from WMATA pointed out that when the system was being designed, there was no maintenance staff. He went on to say that because maintenance

people must be recruited from elsewhere, they may not be familiar with the design of the WMATA track and consequently require orientation.

The committee finally observed that designers should serve the planners, and that perhaps a set of design plans should require a consensus from a transit property. They noted that APTA is examining this area.

2. Investigate the use of guaranteed quantity contracts to reduce construction costs, and conduct demonstration projects in the United States.

The committee felt that as far as they understood what guaranteed quality contracts are, the system is being used. It appears to be similar to unit pricing. Hidden costs involved with minority business enterprise or the state-of-the-market at the time are considered much bigger problems than the quantities.

3. Develop rail for sharp curves that will have increased durability and wear resistance. Investigate the use of manganese steel, hot-forged or cast in short lengths with a rail cross-section, to be bolted or welded to a structural steel base in the event that rolled rails of manganese steel or other very tough alloys cannot be obtained.

The committee agreed that investigation would be valuable and that any investigation should include life cycle costs and welding technology. It was noted that wear-resistance rails have been developed in England and Germany, and that any investigation should start in Europe. One comment was that perhaps we should look at alternatives to hardened steel.

4. Investigate ways to reduce the crushing of ballast between concrete ties and concrete transition slabs.

No one knew of any property having this problem, and therefore no need was seen for an investigation.

5. Investigate the stresses in continuous welded rails on elevated structures in order to obtain valid data to support design assumptions; and develop a standard method for the complete analysis of the sharing and transfer of temperature stresses between elevated structures and continuous welded rail.

The committee agreed that this information would be very interesting, since individual properties have unique problems which call for specific solutions. In the BART system, for example, earthquake forces must be considered. The committee agreed that any investigation that may be conducted should identify each property problem and explain the solution.

One participant stated that better information was needed on rail fasteners and on loading the rail. Another commented that several systems, including BART and WMATA, have problems in determining the stresses in the structures. The committee concluded that the investigation should be designed to gain information rather than for the purpose of setting standards.

6. Investigate the performance of rail fasteners on concrete ties and concrete slabs to obtain data for use in analyses aimed at reducing the size and cost of direct fixation fasteners.

One member questioned whether rail fasteners are over-designed. The consensus was that any investigation in this area would be best spent in documenting the state-of-the-art of fasteners presently available.

7. Investigate possibilities for the continuous support of rails on concrete slabs, in order to avoid stress concentration and other problems associated with discrete fasteners.

The committee agreed that the stress concentrations in transit rail are not that high in comparison to railroad rails, and therefore special investigation is not needed. It was noted that continuous support was being used in Europe, but that adjustment is a problem with PAC system. One member wondered if tolerances could be achieved in the U.S. for continuous support, noting that European tolerances seemed to be much tighter. Another noted that the British use a system in which they press anchor bolts into fresh concrete rather than drilling holes for them, thereby achieving greater accuracy. Other factors in which committee members were interested were drainage (which is a problem in Miami), adjustment and ground-borne vibration.

8. Investigate the use of prestressed concrete slabs for transit track. They offer many advantages in reducing the amount of concrete required, reducing the number of slab joints with their attendant problems, and variations in the strength of subgrades.

The committee considered this technology to be very expensive. It was noted that prestressing the steel introduced problems with anchor bolts and electric circuits. Two systems, the Long Island and Toronto, do have some slab at grade. In Toronto 2000 feet of 11-inch slab track at grade is in successful operation. More information on this track would be very valuable for further planning.

9. Investigate the use of selected sand, confined under slab tracks, in order to reduce the transmission of vibrations to nearby structures. This practice has been effective in some cases other than track and would be less costly than the double slab system.

The committee decided that this would not be a practical approach to the problem and should not be investigated. It was noted that if enough sand to support the load is provided, then it is too stiff to isolate sound vibration.

10. Develop structures for transitions between ballasted embankments and rigid abutments or slabs that will provide a smooth rate of change of track impedance and thus reduce jolts and deterioration of the ballasted track.

The committee noted that this is already being done and further investigation is not needed.

11. Investigate the cost and performance of large steel plate assemblies, floating slabs and special braces as substitutes for wood ties in special trackwork.

The committee was not sure what was meant by the topic. Members did note that MARTA has some special assemblies developed by Transit Products. The excessive wear at National Airport on the WMATA system was also discussed. The system was said to be temporarily overtaxed by the stopping and starting at this location. WMATA is investigating the dynamics of the trucks to find how they wear the special trackwork.

12. Investigate the performance of continuous main rail frogs (jump frogs) used on some properties to reduce wear and noise.

It was agreed that investigation would be very important. Boston is already investigating this subject.

13. Develop and test deceleration bumpers for the end of high speed lines that will stop cars within safe deceleration peaks.

The committee considered this item to be relatively unimportant, noting that it is a problem related more to vehicles than to track.

14. Develop fasteners with a wide range of adjustments for use where slab tracks settle or move beyond expected limits.

The committee decided that it is preferable to design subgrade and slabs so that excessive settlement does not occur. The cost of wide-tolerance fasteners would be prohibitive for settlement that occurs only at a few specific areas. It was noted that elevation can always be adjusted with shims.

15. Determine the effectiveness of fully guarded turnouts in protecting switch and frog points and reducing wear.

The committee considered that fully guarded turnouts did very little to protect switch and frog points and reduce wear. Fully guarded turnouts have some value in keeping car wheels on track. However AREA specifications are generally adequate.

16. Investigate the dynamic effects of construction tolerances in elevated structures and deflections of long members under live load on the ride quality of transit cars, and develop data for design analysis.

This was not considered a problem at typical transit speeds. It was considered a design problem, not a research requirement, and designers should look at specific conditions and structures.

A.2.1.3 Additional Items for Research Proposed by Workshops Members

- Studies of weather-related problems such as 3rd rail icing and snow removal.
- Studies of use or non-use of restraining rail.
- Studies of the relationship of rail wear to stiffness of support and how the impacts cause the wear.

- Nondestructive testing of rail welds to help identify the causes of breaks.
- Investigation of rail interface problems including wheel shape, wheel cant, wheel/rail clearances and duplication.
- A soil mechanics study relating the effects on the subgrade of track vibrations, deflections and loading to determine optimum tie spacing.
- Development of a rail-break detection system.
- A study of restraining rails: how to install them in vertical and horizontal directions; and how to write better specifications with appropriate tolerances.
- A rail corrugation study and better definition of load environment of the rail.
- Dynamic study of the forces acting on fasteners for concrete ties and characterization of fastener loads.

A.2.2 MAINTENANCE WORKSHOP

Chairman: Vincent P. Mahon, Director of Power & Way Maintenance,
Bay Area Rapid Transit District, California

Members:

Deane N. Aboudara, Director
Technical & Research Svcs.
American Public Transit Assn.

Robert C. Belfi
Chief Transit Engineer
City of Philadelphia

Anthony T. Bruno
Senior Project Engineer
ATB Associates

Gilbert L. Butler, Program Mgr
Construction Technology
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Edward G. Cunney
Staff Civil Engineer
ENSCO, Inc.

James F. Delaney
Senior Engineer, Port Authority
of New York and New Jersey

Cecil S. Green
Asst. Superintendent Track
N.Y. City Transit Authority

Warren L. Hale
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Thomas K. Dyer, Inc.

George H. Hayes
Mechanical Engineer
ENSCO, Inc.

Chester Marczewski
Superintendent of Track
N.Y. City Transit Authority

Gregory E. Mester
Chief, Yards, Shops &
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Deleuw, Cather & Company

Thomas O'Donnell, Superintendent
Track & Structures
Washington Metropolitan Area
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Robert Pattison, President
Parsons Brinckerhoff Centec,
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Gerald R. Saulnier
Civil Engineer
Transportation Systems Center

Roy T. Smith, Superintendent
Civil Engineering,
Chicago Transit Authority

Charles Stanford
General Superintendent Track Sec.
Southeastern Pennsylvania
Transportation Authority

Edward J. Ward
Rail Transit Specialist
Transportation Research Board
National Research Council

J.A. Woods, C.Eng.,
Methods Engineer
London Transport International

Donald R. Wolfe
Superintendent Way & Power
Port Authority Transit Corp.

A.2.2.1 Potential Opportunities for Improvements with Current Technology.

These items are listed and comments are summarized in the order in which they were discussed.

1. Provide industrial engineering support to transit properties.

The consensus was that this type of support would be helpful but should be handled on an individual property basis. Industrial engineers work as part of the transit organizations as well as in consulting positions. They are effective when the top people have had track experience, not when they have had only standard training. In one case an industrial engineering department worked well with track supervisors and foremen until it was eliminated in an economy move. Work methods and efficiency studies should be made and standards developed for each maintenance task. Responsibility accounting could be undertaken within the guidelines established under the Financial Accounting and Reporting Elements (FARE) Program. However this accounting

system has not been developed down to work unit reporting and productivity data as was expected. Phase 4 and 5 were planned to cover reporting of operations and maintenance.

Efforts are continuing on accident incident reporting. The Urban Mass Transportation Administration (UMTA), with regulatory responsibility for safety, wants the transit properties to police themselves. A reporting format of the Federal Railroad Administration is under a two-year trial in the collection of accident data for UMTA. Two important questions concern the kind of information that will be collected and how it will be used. A Transportation Reliability Improvement Program (TRIP) has been developed for rail vehicles with a vehicle data base structured to FARE. A similar program may be appropriate for wayside maintenance. A program reporting system is needed.

2. Provide centralized spare parts and rebuild (track components) support.

This was not considered desirable because of the high cost of central organizations. Joint cooperation should be encouraged. Group buying of spare parts is very desirable to minimize costs associated with small orders. There is an industry-wide problem using railroad frogs with relatively small transit wheels, resulting in a 3/16-inch drop in six inches across the flange-ways. Delays of six months to a year can be expected for all supplies, with longer delays for rail. Non-standard sizes add to the problems. In the past BART has obtained 110-lb rail as an add-on to railroad orders, and SEPTA has obtained 100-lb rail as an add-on to NYCTA orders. Purchasing rail is now an enormous problem throughout the country, especially in the East where Conrail and Amtrak have long-term orders at all mills. Even Southern is now buying European rail. Long-range planning for rail renewal is a must.

3. Develop simple guidance for optional use in the management of track maintenance, especially planning, estimating and scheduling.

An industry-wide set of guidelines should be established for track maintenance management. Techniques are needed for evaluating maintenance work in terms of life cycle costing and relating initial costs to long-term benefits. Maintenance planning and scheduling should be related to the use of a test car, and the computer processing of data should be considered.

4. Develop simplified, optional report forms for local control of track inspection and maintenance.

There is a general need for a complete package of standard forms for inspection, programmed maintenance and critical maintenance. This should be tied to items 1, 3 and 6. There is no interest in establishing enforceable track standards but rather track guidelines. The National Design Practices Manual is currently being formulated by APTA and UMTA. London Transport will provide the British code. More research is required. A track geometry task force met in Toronto in November 1977, and recommendations were developed. A copy of those recommendations should be reviewed. The consensus was that the Toronto Track Geometry System (used on revenue cars) is good.

5. Develop incentives for improving track maintenance effectiveness such as awards to properties that make notable improvements.

Incentive awards to properties for improvements in track maintenance effectiveness were not deemed advisable. Administration of awards would be too controversial and difficult.

6. Develop standards for transit track systems, describing in detail what should be measured.

The consensus was to change "standards" to guidelines and recommended practices. The APTA subcommittee on Track and Structure has been working on guidelines.

7. Provide guidance on inspection techniques, "how to do it" information for inspectors.

The consensus was that such guidance is needed. Track geometry (TG) and ride quality measurements should be coordinated with other inspections such as the measurement of rail wear. The Iowa Hy-Railer was mentioned. However it collects unloaded TG data from contact sensors and cannot be used in revenue service. NYCTA found the 116 car exposed problems that were not found by inspectors and is obtaining an EM80 track survey car which will be modified to fit clearances. BART has ordered a Matisa vehicle modified for wide gage. Much research and training are needed for proper interpretation of track geometry data, as strip charts seem to be too voluminous. The Japanese National Railway is using car accelerations as a basis for inspecting contract work and planning maintenance. Southern Railway has correlated derailment tendencies with alignment deviations and twist.

A uniform system for marking track distance may be desirable; at least standard reflecting markers could be purchased at lower prices in large quantities.

A standard survey car for all transit systems would be desirable, but gage and clearance differences make this unlikely. Documentation from a survey car is useful in management overview as well as in maintenance.

A track inspection package should indicate data to collect and how to analyze and use it. Rotation of inspectors is a good technique to obtain a fresh point of view. London Transport uses a special team to inspect all track at intervals and check routine inspections.

Railroads are trying to go from TG to performance standards. Ride quality would be one measure of performance. Acceleration thresholds are to be identified that correlate with TG exceptions. A portable ride quality package was thought to be a good, inexpensive concept, since the transit vehicles are similar, and it could be used on all of them.

8. Support the further development of training courses and seminars. A possibility is the arrangement of training at large properties for people from small properties.

The committee agreed on this topic. Industry-wide training programs for track foremen were deemed necessary. The Conrail program initiated by Ford, Bacon & Davis and continued by Schaffer Associates was described as a model program whose classes are conducted by Conrail personnel. UMTA could fund this program for transit personnel.

9. Support demonstration projects to validate the effectiveness of favorable track maintenance practices.

The committee supported this idea and noted that it is being done in the case of concrete ties.

A.2.2.2 Potential Opportunities for Improvement that Require Research or Investigation

These items were discussed as follows.

1. Develop a portable ride quality recording system to identify changes in track condition and provide the M/W superintendents with information for decisions on the priority of track maintenance work.

This was discussed under Item 3 on the current technology list. It was agreed that a system should be developed, and this item was assigned a high priority.

2. Investigate the availability of track for maintenance work, including all effects on costs and operations, and develop guidance for the most favorable practices.

The committee agreed on this. A study should be made of maintenance costs and track availability to verify the dollar value of track time. Designers for new tracks and track rehabilitation should include features that will help arrangements for track availability. The comments under item 2 in the list of maintenance practices were also considered applicable. This was assigned a low priority.

3. Develop a cost-effective, in-place treatment for deteriorated ties, using available fungicides, fillers and protective coverings in order to extend the useful life of the ties and defer the high costs of replacements.

The committee agreed on this proposal, stating that a simple, low-cost method is needed. It was assigned a low priority.

4. Develop a small vibratory ballast compactor to stabilize ballast in the cribs and shoulders of resurfaced track and thus help to hold line and grade.

The committee disagreed with this suggestion. Members noted that suitable equipment is available, although some adaptation may be necessary.

5. Investigate in depth all current practices and available techniques to extend the useful life of rail on curved transit track, and develop guidance for cost-effective practices.

The committee agreed with this proposal. The comments under maintenance practices, item 17, were considered relevant. The item was assigned a low priority.

6. Investigate the maintenance of CWR and BJR on curves and short tangents, and develop guidance for the cost-effective use of the two types of rail joints.

The committee supported this item, noting that studies should find the break-even points (curve radius and length) for maintenance costs. These will vary in relation to traffic and other factors. The item was assigned a medium priority.

7. Investigate the relation of the transverse wheel tread profile to rail wear, and develop guidance for grinding wheels.

The committee agreed with this proposal. Members commented that AAR standards should be reviewed. It was noted that false flanges that develop on wheel treads near the outside edge, pick up worn switch points and damage them. Another comment was that the problem should be discussed with car shop superintendents and designers. This item was assigned a low priority.

8. Follow-up studies by the Federal Railroad Administration on the use of steerable trucks to reduce wear of rail and wheels on curves; relate the findings to transit track requirements and perform such additional studies and tests as are necessary to obtain the benefits for transit track.

The committee favored this suggestion, noting that UMTA is requesting bids on a project to build a steerable truck. This item was assigned a high priority.

9. Investigate corrosion of rail and other track components, and develop guidance on effective methods to reduce the rate of corrosion.

The committee agreed with this suggestion. Corrosion of bolts and components was noted to be very troublesome. The item was assigned a medium priority.

10. Develop improved methods and tools for track inspection in order to reduce tedious work and obtain better results.

The committee agreed with this item which is related to ride quality system, Item 1, and other inspection items. It was assigned a medium priority.

11. Develop favorable methods for smoothing line and grade of track on elevated structures that have large construction tolerance or have shifted since construction.

The committee agreed that this is a good suggestion, although it is a problem area on only a few properties. Members commented that laser beams may be useful in establishing reference line, and some track liners may be useful on elevated track. The FRA Track Survey Device may also be valuable. The item was assigned a low priority.

12. Develop improved hand tools for trackmen that will provide more job satisfaction and encourage more interest in the work.

The committee agreed on this item, noting that some tools are awkward and cumbersome to use, especially in confined spaces. The item was assigned a low priority.

A.2.2.3 Three Research Items Proposed by the Workshop Group

These items requiring extensive investigation and tests are:

- Track welding process. The need for research on welding was considered very important.
- Switch maintenance, switch point and frog rehabilitation.
- Electric switch heater installation on switch points and guard rails.

A.2.2.4 Favorable Maintenance Practices in Limited Use

Practices were discussed that had been observed in a few transit systems. Many of these practices have been developed or modified by individual transit properties to suit their specific needs. Some of the transit properties are using most of the practices and items noted below; all are using some of them. Wider use of such practices with modifications to suit special needs of the properties would help increase the effectiveness of track maintenance. The consensus of the workshop members (with few exceptions) was that the practices are good ones and should be used. Special comments were made on only a few of the items as noted.

1. Tightening maintenance planning and scheduling helps increase preventive and routine maintenance while reducing emergencies and reducing the frequency of major replacements.

It was noted that each property has special conditions and needs.

2. Increasing uninterrupted track availability time for maintenance helps improve maintenance productivity and quality.

Availability of track time for maintenance is a general problem especially on properties that operate 24 hours a day. Designers and operations staff should consult to locate cross-overs and associated signal systems to facilitate redirection of traffic to allow for the maintenance or repair of track. Several properties have been able to provide bus service to make track available for long periods of maintenance work.

3. Strengthening maintenance control will help improve quality.
4. Stacking similar maintenance jobs will generally increase both quality and productivity. The scheduler stacks the jobs so that they are in the same general area without excessive travel between jobs, they can be done consecutively without backtracking, and there are no interruptions by other types of work that require different materials, equipment and tools.
5. The use of standard "How to do it" job instructions provides good basis for planning, doing and supervising track maintenance work.
6. Use of standard, "How to do it" instructions helps increase the effectiveness of all track inspections.
7. Encouraging track mechanics to provide ideas for improving maintenance and inspection instructions helps everyone to do a better job.
8. Augmenting the formal training of track mechanics and supervisors will assist them to improve the quality of track maintenance work.
9. Well planned and consistent policies to control absenteeism are helpful in improving the reliability of the maintenance forces.
10. Inspecting and reporting all completed maintenance work gives recognition to track mechanics and encourages them to improve the quality of their work.

This is a quality assurance item.

11. Inspecting tracks and components on regular schedules, related to the amount of traffic and frequency of problems, helps planners and supervisors to adjust to maintenance efforts to the needs.

Items 11, 12 and 14 are closely related. The signal and M/W people of many properties inspect switches and obstructions jointly at 30 day intervals. Every third inspection is expanded into a detailed check of the entire switch mechanism. Switch inspection reports are mandatory.

12. Rotating inspectors changes the bias in track inspections, and comparisons of reports provides a clearer picture of track conditions.
13. Using tools to measure track problems seen or suspected during inspections will reveal changes occurring in track structures. The measurements should include rail irregularities, tie cutting, displaced pads, wide joint gaps, end batter, spalls, misalignments, slack in switch mechanisms, deflection of switch heels under traffic, and wear of frogs and switch points.
14. Reporting all inspections on short, standard forms helps ensure high quality inspection and timely follow-up actions.
15. Documenting and reporting failures of equipment and tools will help avoid the continuing purchase of inadequate items.
16. Standard procedures and records for the trial of new material or equipment will support good decisions on changes.
17. Transposing worn rail, to get more out of it before replacing it, will usually help hold down maintenance costs.

In some cases, the labor costs for transposing rail were three times as high on curves as on tangent track. Grinding off and installing new bonds on the rib (field) side of the rail are expensive. In some cases the rail to be transposed can be moved ahead to a reverse curve and used without changing bonds.

18. The use of hardened steel rails, lubricators, restraining rails, reduced speed, superelevation and gage widening are all thought to help reduce the rate of wear in curves. Good local records will provide facts to support decisions on possible changes.

It was agreed that wear of rails in curves can be reduced considerably by the suggestions (hardened steel rails, restraining rails, reduced speeds, superelevation and gage widening); lubricators require a training program to assure proper distribution of lubricants.

There are many problems in rail wear, and intensive study is needed. For example SWPTA has had some fully heat treated rail on sharp curves that wore out (gage side) as fast as plain rail did.

UMTA is currently requesting bids on a steerable transit truck; its implementation should help considerably. Chrome-moly was mentioned as the best new alloy available for rail steel. The UMTA track at the Pueblo Transportation Test Center may be valuable in testing practices. BART is going to try some 119-1b. chrome alloy rail on curves. Using summer and winter grade lubricants and adding a control valve on lubricators for adjustment by inspectors has helped at NYCTA. Special, extra training is needed.

19. Measurements and records of rail corrugations and grinding provide valuable support for decisions on the extent of rail grinding.
20. Replacing bolted joints with welded joints reduces periodic joint maintenance and the maintenance of ballasted roadbeds.
21. Periodic lubrications and torquing of joint bolts to specified tension, plus frequent inspection and retightening as needed, are necessary to keep the bolts tight. Special glues will help keep them tight.
22. Excessive wear of the joint bars and rail can be avoided by lubricating the fishing surfaces and keeping the bolts tight to specified tensions.
23. The frequency at which joint bolts break can be reduced by replacing deteriorated ties, keeping the ballast firmly tamped at joints, lubricating fishing surfaces and keeping bolts tight.
24. The number of bolts that break in restraining rails and special trackwork can be reduced by using high strength and/or large size bolts.
25. Corrosion in subways and tunnels can be reduced by sealing leaks, improving drainage and oiling with rust inhibitors.
26. Wide gaps at a few bolted joints can be reduced by regapping the rails, oiling the fishing surfaces, keeping bolts torqued to specified tension and improving rail anchorage.

27. Spalling rails at bolted joints can be avoided by cross cutting to remove flowed material from the top and sides of the rail ends at bolted joints. It can be corrected by welding and grinding.
28. The number of fires that ignite in debris accumulated in the cracks of old wood ties can be reduced by early replacement of the ties or filling the cracks.
29. Frequent adjustment and tamping of ballast adjacent to slab track and abutments helps slow the rate of track deterioration.
30. Prompt cleaning of clogged drainage and fouled ballast helps reduce the rate of track deterioration in all cases.
31. The shorting of signals by metallic dust at insulated joints can be eliminated by bonding the joints with epoxy so as to fill all crevices.
32. Lateral movement of tracks on curves can be reduced by heavy ballast (trap) in large sizes. Timbers have been fastened across the ends of ties in the ballast to resist lateral movements.
33. Good drainage and a subballast carefully graded to filter out fine material help avoid mud pumping in ballasted track.
34. Loosening the bolts at low joints and straightening bent joint bars are essential for obtaining good results from surfacing ballasted track.
35. Shimming to remove open space between rail and fastener, or fastener and slab, reduces the breaking and pullout of fastener bolts.

APPENDIX B

COST-BENEFIT ANALYSES OF CANDIDATE RESEARCH AND SUPPORT TASKS

G.1 GENERAL

As discussed in Section 8 of the report, a life cycle of 50 years and a 10% interest rate are used in the analyses of candidate tasks. The 50-year life cycle is based on experience with the overall durability of transit systems, the very low present values of savings or costs that will not be realized until 50 years in the future, and uncertainties in predicting conditions that will affect future costs and levels of use.

The complicated effects of inflation are omitted from the analyses on the simplistic assumption that all costs and values will rise at approximately the same rate. While the cost of energy is recognized as a major exception, a continuing rise of energy costs at an above the average rate will tend to increase the benefits of savings in work and materials. Another simplification is to compound interest annually on the assumption that the cash flow will be uniform year-end cash flow. This is reasonable, since the costs used are broad, nationwide approximations rather than the detailed cost estimates that would be used in planning a project for one transit property at a specific time.

The benefits to be obtained from a research task at any one property are affected by a large number of local factors. Perhaps the most important of these local factors is the present level of efficiency of the maintenance of way organization. Other factors include: present condition of the system, traffic level, operating costs, wage rates, available skills and spare parts support. Because of the variability of local data, the average costs and quantities have been estimated conservatively in an effort to avoid overstating the benefits that may accrue from a candidate research task.

Candidate tasks that affect a specific track component are evaluated in terms of the benefits that may accrue from reducing the cost of that component, extending its useful life in track or simplifying its replacement, and the number of components in use. Candidate tasks that affect overall efficiency are analyzed for benefits that may accrue from raising the average cost effectiveness of track maintenance.

Approximately 2700 people are employed nationwide in the maintenance of way (less power) for transit systems. It is difficult to determine how much of their time is spent in the maintenance and repair of track versus other way structures. A conservative estimate would be at least two thirds of the time is spent on track work and its support. This the equivalent of 1800 people.

Direct pay plus benefits and other overhead costs average approximately \$22,500 per person per year, a total of \$40.5 million. Track components, consumables, repair and replacement of equipment, and other materials support cost approximately half the total labor costs. Thus current transit track maintenance and replacement costs are over \$60 million dollars per year, including yard track. This figure is in reasonable balance with the current replacement costs of the track. This is estimated at an average of \$150 per linear foot for 1600 equivalent miles of single track including yard track but not structures such as viaducts, bridges and tunnels. Total track replacement cost is: $150 \times 1600 \times 5280 = \1270 million. The ratio of annual maintenance cost to current replacement cost is then: $60/1270 = 4.7\%$.

It should be noted that a percent gain in efficiency is not equivalent to the same percent savings or increase in value. At the lower end of potential gains in efficiency, a 2% gain would produce an equivalent savings (or value increase) of:

$$\text{cost} - \frac{\text{cost}}{\text{efficiency}} = 1.00 - \frac{1.00}{1.02} = 1.96\% \text{ savings}$$

At the higher end, a 100% gain in efficiency would produce an equivalent savings (or value increase) of:

$$1.00 - \frac{1.00}{2.00} = 50.0\% \text{ savings}$$

Candidate tasks that were identified as important are discussed in the analyses that follow. Each is identified with the number assigned to it in Table 9, page 107.

TASK No. 1: Investigate the Use of Guardrails at the Ends of Station Platforms, Through-Girder Bridges and Other Obstructions

OBJECTIVE: Determine the effectiveness of guardrails in preventing cars from colliding with wayside obstructions.

Sub-Objective: Compile data on the causes of derailments and their costs.

TARGETS: Costs -- Investigate causes and probabilities of derailments, and the costs and effectiveness of guardrails, and develop conclusions at a cost of not more than \$80,000.

Time -- Complete the investigation, analyses and report within 10 months of contract award.

SITUATION: Derailments may be caused by track defects or car defects and by combinations of both. A guardrail is installed to hold the wheels of derailed cars to a path between it and the adjacent running rail, so that the cars cannot move away from the line of the track and hit wayside obstructions. It also helps prevent derailed cars from running off an elevated structure or embankment. Equipment that hangs below cars and is below the top of rail after a car has derailed, performs a similar function.

In addition to direct costs, derailments may have high costs in factors that affect transit system performance such as adverse publicity, passenger attitudes and regulatory actions.

Guardrails cannot be expected to reduce the costs of minor derailments where there are no obstacles for cars to hit; but they can be expected to reduce potentially serious derailments to a minor level, by holding the cars along the line of the track and preventing them from hitting wayside obstacles or running off elevated structures or embankments.

Reported derailments are few and far between, and the probability is very low that a derailed car will hit a wayside obstacle or run off an elevated structure even without a guardrail at the derailment site. However the marks of derailments seen on track structures and informal discussions have indicated that as many as three derailments can be expected each year which would be serious if not controlled by guardrails. From this, a rough indication can be obtained that guardrails are valuable where they are installed near obstacles on existing systems.

The average cost of a serious derailment is assumed to be \$500,000, and the average minor derailment is assumed to cost \$20,000 as discussed under task 13 for a rail break detection system. With three potentially serious derailments a year, the benefits of the installed guardrails may save as much as:

$3(500,000) - 3(20,000) = \1.4 million per year savings in derailment costs.

The miles of guardrails in use at the ends of station platforms, through-girder bridges and other wayside obstacles have not been measured, but the total appears to be in the range of 200 miles. The replacement cost of these guardrails (with used rail or structural steel angles) would be approximately \$14 per foot. However they have a useful life equal to the 50-year life cycle of the track and require no maintenance unless damaged by derailed cars, dragging equipment or corrosion. Their cost per year then would be:

$$\begin{aligned} \text{Annual cost} &= \text{replacement cost} \left(\frac{i}{1 - (1+i)^{-50}} \right) \\ &= 200 \times 5280 \times 14 \left(\frac{0.1}{1 - 1.1^{-50}} \right) \\ &= \$1.5 \text{ million (rounded)}. \end{aligned}$$

These very rough approximations are not conclusive. In addition, the benefits of guardrails for total transit system performance may far exceed the benefits that can be estimated in the reduced severity of derailments. Since the primary issue is safety, the effectiveness of guardrails should be investigated in detail.

TASK No. 2: Review, Clarify and Summarize Available Information on the Use of Protective Sand Filters and Filter Fabrics in Track Structures.

OBJECTIVE: Provide information on protective sand filters and filter fabrics for the use in track design and maintenance.

Sub Objective: Identify needs for developing improved methods of repairing track in which mud pumping has occurred.

TARGETS: Costs -- Complete review and report at a cost of not more than \$25,000.

Time -- Finish task within 8 months of contract award.

SITUATION: Problems and track failures in ballasted track, slab track at-grade, and transition slabs between rigid structures and ballasted track have been observed where mud pumping occurs. Both protective sand filters and filter cloth are used to prevent the ballast or concrete from being forced down into wet soil below it, and to prevent fine soil mixed with water being pumped up under the concrete or up through the interstices of the ballast. Although mud pumping has occurred infrequently in transit track, the costs of repairs are very high, and some of the work has not been fully effective. Definitive information on the use of sand filters and filter fabrics is not readily available to track designers and to maintenance supervisors.

ANALYSIS: Observation of conditions in ballasted track both in lines and yard indicate that, on the average, approximately one mile of track per year would require repairs because of mud pumping. However the repair sites will be small and at widely scattered locations. Consequently, the unit repair costs will be high, in the range of \$50 per track foot (without rail replacement) and some of the work will be ineffective. Total costs of this work are then expected to be approximately \$300,000 per year.

It is considered probable that the provision of good, clear information on the best construction and repair techniques available will assist M/W superintendents to improve the cost-effectiveness of repair work by 20% as well as reduce the frequency of the problem in new track. This would save or offset rising costs by:

$$300,000 \left(1.00 - \frac{1.00}{1.20} \right) = \$50,000/\text{yr.}$$

These savings would be expected to begin 1 year after the end of the task.

The present value of the savings over a 50-year life cycle starting at the beginning of the task would then be:

$$\begin{aligned} PV &= S \left(\frac{1 - (1+i)^{-50}}{1+i} - \frac{1 - (1+i)^{-1}}{(1+i)} \right) - 25,000 \\ &= 50,000 \left(\frac{1 - (1.1)^{-50}}{0.1} - \frac{1 - (1.1)^{-1}}{0.1} \right) - 25,000 \\ &= \$430,000 \text{ (rounded)}. \end{aligned}$$

TASK No. 3: Investigate Coordination of Planners, Designers, Contractors and Maintenance Engineers on Design, Construction and Maintenance.

OBJECTIVE: Enhance the life-cycle cost effectiveness of transit track by assisting planners, designers, contractors and maintenance engineers to coordinate and pool their ideas and requirements.

Sub Objectives: Prepare check lists of actions that tend to simplify and improve coordination.

Prepare check lists of track features that have increased life cycle cost effectiveness and features that have reduced it.

TARGETS: Costs--complete investigations, guidance and report at a cost of not more than \$130,000.

Time--complete work within 14 months of contract award.

SITUATION: Coordination and cooperation are good in most cases, but even small improvements may have a very high value over the life cycle of the track.

As-built transit tracks vary greatly in durability, maintainability and in overall cost effectiveness. Most track features that increase durability and/or maintainability so as to reduce future maintenance costs also increase construction costs. Examples are long-radius curves and wide clearances. However some features in tracks and adjacent structures can be arranged to enhance maintainability with little or no increase in construction costs. Examples are the use of track components that are widely used by railroads in the local area, provision of convenient access to the tracks switching arrangements that facilitate single track operation so that adjacent tracks can be closed for maintenance work.

ANALYSIS: The current cost of constructing transit track (not including related structures such as tunnels, bridges, and viaducts) exceeds \$150 per track foot. Current construction and plans indicate that approximately 10 miles of new track and 10 miles of replacement track will be built each year in the foreseeable future, at a cost of approximately \$16 million (1979 dollars) per year.

Maintenance of the present 1600 miles of line and yard track costs approximately \$60 million per

year. However any increases in track durability and maintainability that could be obtained as a result of this task could affect only the new track and replacement track being built at an estimated rate of 20 track miles per year. The normal maintenance cost of this annual increment of track would be:

$$20 \times \frac{60}{1600} = 0.75 \text{ million}$$

In the second year two increments of track would be maintained at \$150 million; the third year, three increments would be maintained and so on. The present value of the normal maintenance cost of all track expected to be built during the next 50 years would then be:

$$\begin{aligned} PV &= 0.75 [(1+i)^{-1} + \dots + {}^{50}(1+i)^{-50}] \\ &= 0.75 \left[\frac{1}{1.1^1} + \dots + \frac{50}{1.1^{50}} \right] = 75 \left[\left(\frac{1}{1.1} \right)^1 + \dots + {}^{50} \left(\frac{1}{1.1} \right)^{50} \right] \\ &= 0.75 \int_0^{50} n \text{ nr}^n \text{ dn} \\ &= 0.75 \int_0^{50} n e^{an} \text{ dn} \quad \text{where } e^a = r = \frac{1}{1.1} \\ &\quad \text{(Taking the natural logarithms of both sides of this equation gives: } a = -0.09531.) \\ &= 0.75 \left[\frac{e^{an}}{a^2} (an - 1) \right]_0^{50} \\ &= 0.75 \left\{ \frac{e^{50a}}{a^2} (50a - 1) - \frac{1}{a^2} (-1) \right\} \\ &= \frac{0.75}{a^2} [e^{50a} (50a - 1) + 1] \\ &= \frac{0.75}{0.00955} = 79 \text{ million (rounded)} \end{aligned}$$

The present value of a 1% improvement in the maintenance of the new and replacement track that is built would then be:

$$79 \text{ million } (1.00 - \frac{1.00}{1.01}) = \$780,000$$

Subtracting the cost of the task leaves a net present value of:

$$\$780,000 - 130,000 = \$650,000 \text{ (rounded).}$$

It is considered probable that a formal study will assist the interested parties to obtain improvements totaling more than 1% during a few years of efforts.

TASK No. 4: Develop Rail with Very High Resistance to Wear in Curves.

OBJECTIVE: Extend the useful life of rail in curves by 200 percent.

TARGETS: Costs -- The new, wear-resistant rail should not cost more than 4 times as much as high-carbon, heat treated rail.

-- Determine the composition and structural form of the new rail at a research cost of not more than \$200,000.

-- Fabricate 4 prototype (demonstration) rails at a cost of not more than \$80,000.

Time -- Complete all studies, fabrication and demonstrations within 3 years of the contract award.

CONSTRAINTS: Use proven materials that are available in commercial quantities. Do not increase the wear of car wheels.

SITUATION: The annual costs for hardened steel rails in curved transit track are very high. In an analysis of a candidate research task to determine the most beneficial combination of current practices to reduce rail wear, an estimate of \$790,000 per year is given as the current replacement cost of rails in sharp curves. There are approximately 10 miles of curves < 300-foot radius in U.S. track. The high-carbon steel used in these rails has low fracture toughness which contributes to rail flaw problems, and it loses hardness when heated which contributes to accelerated wear at welds.

Several alloy steels are available that have high wear resistance and much greater fracture toughness than high-carbon steel does.

Manganese steel is widely used to resist wear in frogs and switch points and has been used for rails on curves in British transit and railroad track. Chrome-molybdenum steel and other alloy steels may also be suitable for rail in curved track.

ANALYSIS: As noted in the analysis of the task for determining the best combination of current practices to reduce rail wear, the high rails on curves < 300-foot radius cost approximately \$4,000 to replace and have an average service life of 2.5 years; the restraining rails cost approximately \$5,600 to replace and have a service life of approximately 4.0 years.

The annual cost of replacing the rails is:

$$\frac{10 \times 5280}{200} \left(\frac{4000}{2.5} + \frac{5600}{4} \right) = 264 \times 3000 = \$790,000$$

The present value of these costs over the 50-year life cycle of the transit systems is:

$$\begin{aligned} PV &= 790,000 \frac{1 - (1 + i)^{-50}}{i} \\ &= 790,000 \frac{1 - 1.1^{-50}}{0.1} = \$7.8 \text{ million} \end{aligned}$$

The 200 linear feet (LF) of 115-lb., heat treated rail costs approximately \$1500 (in large quantity purchases). The 200 LF of restraining rail costs approximately \$1500 + \$600 because of the cost of shearing off one side of the bottom flange. Assume the more durable rail will not add to the \$600 cost of finishing the restraining rail or to the cost of labor for installing the rails, then the high rail will cost installed a maximum of
 $4 \times 1500 + 2500 = \$8500$ and will last $2.5 \times 3 = 7.5$ yrs.
and the restraining rail will cost:
 $4 \times 1500 + 600 + 3500 = \10500 and will last $4 \times 3 = 12$ yrs.

Assuming that more durable rails become available 4 years from the time of project approval, the existing high rails would be replaced with the more durable rails by $1979 + 4 + 2.5$, and the existing restraining rails would all be replaced by $1979 + 4 + 4$.

Then through $1979 + 4$, the cost of replacing the rails would be \$790,000 per year. From $1979 + 4$ through $1979 + 6.5$, the cost of replacing the high rails alone would be:

$$264 \times \frac{8500}{2.5} = \$897,600/\text{yr.}$$

From $1979 + 6.5$ through $1979 + 50$ the cost of the high rails would be:

$$264 \times \frac{8500}{7.5} = \$299,200/\text{yr.}$$

From $1979 + 4$ through $1979 + 8$ the cost of replacing restraining rails would be:

$$264 \times \frac{10500}{4} = \$693,000/\text{yr.}$$

From $1979 + 8$ through $1979 + 50$, the cost of restraining rails would be:

$$264 \times \frac{10500}{12} = \$231,000/\text{yr.}$$

The present value of these repetitive costs is:

$$\begin{aligned}
 &790,000 \frac{1-1.1^{-4}}{0.1} + 897,600 \left(\frac{1-1.1^{-6.5}}{0.1} - \frac{1-1.1^{-4}}{0.1} \right) \\
 &+ 299,200 \left(\frac{1-1.1^{-5.0}}{0.1} - \frac{1-1.1^{-6.5}}{0.1} \right) \\
 &+ 693,000 \left(\frac{1-1.1^{-8}}{0.1} - \frac{1-1.1^{-4}}{0.1} \right) \\
 &+ 231,000 \left(\frac{1-1.1^{-5.0}}{0.1} - \frac{1-1.1^{-8}}{0.1} \right) =
 \end{aligned}$$

$$2.50 + 1.30 + 1.58 + 1.06 = \$7.9 \text{ million (rounded).}$$

Add to this the research and development costs and the total is \$8.20 million (rounded), which is \$0.4 million more than the present value of costs associated with the continuing use of rails now available for curved track.

At current high interest rates, this candidate task would not be beneficial unless the improved rail were much more durable and/or cheaper than expected.

TASK No. 5: Investigate the Stresses in Continuous Welded Rail (CWR) on Elevated Structures and the Transfer of Stresses Between Rail and Structures.

OBJECTIVE: Provide data to facilitate the safe use of CWR on open-deck elevated structures.

Sub Objective: Determine by field tests the stresses in CWR on elevated structures and the transfer of stresses between CWR and support structures.

TARGETS: Costs -- Complete investigations, tests, and reports at a cost of no more than \$150,000.

Time -- Complete all work within 18 months from the date of contract award.

SITUATION: Over 325 miles of transit track (without ballast) are built on elevated structures or bridges. More is planned. Of the existing track 257 miles are on open-deck structures with bolted rail joints. Conversion to continuous welded rail (CWR) would be advantageous in reducing maintenance at joints, reducing noise and increasing ride quality. However engineers are concerned that the transfer of thermal and braking stresses from rail to structure could cause high stress concentrations, particularly when superimposed on normal dynamic stresses. In addition there are uncertainties in the distribution of stresses between existing CWR and elevated structures of reinforced concrete or composite construction. These uncertainties arise from the range of longitudinal restraint provided by the fasteners and other factors and may result in stress concentrations that will cause structural distress in some cases.

Maintenance at bolted joints is considered to comprise over half of the routine cost for ballasted track on embankments but is a much lower percent of the maintenance of track on a steel or concrete structure, say 20%. Welding the joints would greatly reduce joint maintenance, say to 8% of the total track maintenance, a reduction of 12%.

Approximately 80% (205 track miles) of the elevated rail could be welded if good data were available on stress transfer. The remaining 20% of the rail is considered to be in curves of short radius (where bolted joints would be favorable because of the frequent replacement of worn rail) or on structures that would not be suitable for CWR.

The current average cost of maintaining track is approximately \$60 million/yr for 1600 miles of line and yard track, an average of \$37,500 per track mile/yr. A reduction of 12% by the conversion from bolted to welded joints would represent a savings of \$4500 per mile for the 205 miles of track suitable for CWR on open-deck elevated structures. This cost reduction would continue year after year throughout the life cycle of the track but would be reduced by the initial cost of cropping rail ends and welding.

The rail welding could probably start within three years of the start of the task and would cost approximately \$100 per joint, using the flash butt welding process, and including the cost of rail to make up for cropped ends. When the welding is in full progress, approximately 25 miles of track could be welded per year. Welds would be approximately 36 feet apart in the rail (39-ft rails with ends cropped) or 18 feet apart in track. The average cost per track mile would then be

$$\$100 \times \frac{5280}{18} = \$29,330$$

Half of the task costs would be incurred by the end of the first year of the task and half by the end of the second year. To simplify the analysis all cash flow is considered to take place at the end of each year. Estimated costs and savings can then be calculated in thousands of dollars as follows:

Year	1	2	3	4	5	6	7	8	9	10	11	12
Miles	0	0	10	25	25	25	25	25	25	25	20	
Welded (cumulative)				10	25	60	85	110	135	160	185	205
Costs	75	75	293	733	733	733	733	733	733	733	587	
Savings				45	158	270	383	495	608	720	833	923
Net	-75	-75	-293	-688	-575	-463	-350	-238	-125	-13	246	923

The \$923,000 net cost reduction would continue from year 12 through year 50.

The present values of the net costs and savings are calculated in thousands of dollars and summed as follows:

$$\begin{aligned}
 PV &= -75(1+i)^{-1} - 75(1+i)^{-2} - 293(1+i)^{-3} - 688(1+i)^{-4} \\
 &\quad - 575(1+i)^{-5} - 463(1+i)^{-6} - 350(1+i)^{-7} - 238(1+i)^{-8} \\
 &\quad - 125(1+i)^{-9} - 13(1+i)^{-10} + 246(1+i)^{-11} \\
 &\quad + 923 \left(\frac{1 - (1+i)^{-50}}{i} - \frac{1 - (1+i)^{-11}}{i} \right) \\
 &= -75 \times 1.1^{-1} - 75 \times 1.1^{-2} - 293 \times 1.1^{-3} \\
 &\quad - 688 \times 1.1^{-4} - 575 \times 1.1^{-5} - 463 \times 1.1^{-6} \\
 &\quad - 350 \times 1.1^{-7} - 238 \times 1.1^{-8} - 125 \times 1.1^{-9} \\
 &\quad - 13 \times 1.1^{-10} + 246 \times 1.1^{-11} \\
 &\quad + 923 \left(\frac{1 - 1.1^{-50}}{0.1} - \frac{1 - 1.1^{-11}}{0.1} \right) \\
 &= \$1.5 \text{ million (rounded)}.
 \end{aligned}$$

Half of this projected savings could be wiped out by an increase in estimated welding costs (1979 dollars) from \$100 to \$125. However, the improvement in ride quality and reduction of noise would both be valuable, and some small savings may be feasible in the construction of new elevated track when better data on the transfer of stresses is available for designers.

TASK No. 7: Investigate Track Problems Caused by Severe Weather Conditions, Damage Control and Recovery, Phase I.

OBJECTIVE: Define needs, scope, cost and value of a task to develop guidance on practices to minimize the effects and costs of weather problems.

Sub Objectives: Obtain data on costs, damage control and recovery, and the effects of track conditions on system performance that will be useful in other tasks.

TARGETS: Costs -- Complete the investigation and report at a cost of not more than \$30,000.

Time -- Complete all work within 8 months of contract award.

SITUATION: Severe weather conditions, especially heavy snow storms, disrupt transit traffic and raise the cost of system maintenance. Weak preventive measures and slow recovery from the effects of storms cause passenger dissatisfaction and loss of revenue. The ranges of conditions, costs and actions taken to reduce or correct problems have not been studied. Information is needed on which to base plans for the development of effective guidance on favorable practices for the control of and recovery from storm damage. The information will be valuable also in considering needs for other damage control and recovery guidance.

This is a preliminary task, and data is not available on which to base an analysis of its value.

TASK No. 13: Develop Rail Break Detection System

OBJECTIVE: Provide information on rail continuity automatically.

Sub-Objective: Develop a rugged, low-maintenance, sensing and display system with a self-monitoring capability.

TARGETS: Costs -- Investigate requirements and conditions, and develop concept plan at not more than \$100,000.

-- Design, fabricate, install and test prototype system at not more than \$275,000.

Time -- Develop concept plan within one year of contract award. Test prototype within 2 years of authorization to proceed.

CONSTRAINTS: Detection system must not interfere with other track signals and controls.

SITUATION: The probability of a rail break occurring is very small. Rail breaks occur very infrequently at welded joints during cold weather and hardly ever at other places in a rail in transit system rails. Information obtained informally by a London Transport representative in Europe indicated that 10-to-30 rail breaks can be expected per year in systems with new CWR, but this frequency can be expected to diminish rapidly as the joints that separate are repaired and the internal flaws that caused the breaks are eliminated.

Tracks are designed to limit the separation that will occur if a joint fails in cold weather, so that a derailment will not occur. Track and cars are designed with characteristics that are intended to limit the seriousness of a derailment that could occur as a result of a rail break. A serious derailment is tentatively defined as one that would result in damage and/or claims for injuries amounting to more than \$100,000. The average serious derailment may cost over \$500,000. The average minor derailment may cost approximately \$20,000.

Informal discussions have indicated that as many as ten rail separations per year may be expected in U.S. transit tracks, that on the average only one of these will cause a minor derailment, and that serious derailments are unlikely to occur more often than once in five years as a result of rail separations. From this a derailment cost of \$120,000 per year can be assumed. This does not include the cost of adverse publicity and passenger reaction.

It assumed that fully effective rail break detection systems would eliminate derailments caused by rail separations, that they would cost approximately \$1.4 million to install at \$1,000 per track mile, and they would be effective two years after the completion of the task. Savings would then accrue beginning in the fifth year after initiation of the task, would reach a \$12,000 level in the sixth year and would continue throughout the 50-year cycle of the track. For analysis purposes, this 50-year life cycle begins when the task is started.

The present net value of the task calculated in thousands would then be:

$$\begin{aligned}
 PV &= -100 (1+i)^{-1} - \frac{275}{2}(1+i)^{-2} - \frac{275}{2}(1+i)^{-3} \\
 &\quad + \frac{120}{2}(1+i)^{-5} + 120 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-5}}{i} \right) \\
 &= -\frac{100}{1.1} - \frac{2.75}{2 \times 1.1^2} - \frac{2.75}{2 \times 1.1^3} + \frac{1.20}{2 \times 1.1^5} \\
 &\quad + 120 \left(\frac{1-1.1^{-50}}{0.1} - \frac{1+1.1^{-5}}{1} \right) \\
 &= \$560,000 \text{ (rounded)}.
 \end{aligned}$$

TASK No. 17: Provide Continuing Industrial Engineering Support to Maintenance-of-Way (M/W) Superintendents.

OBJECTIVE: Improve the cost effectiveness of track maintenance by nine percent over a period of five years.

Sub Objectives: Adapt and modify available maintenance methods to suit local conditions.

Provide information to top management that will clearly relate track maintenance to transit system performance.

Develop outlines, check lists and other guidance to suit M/W needs.

Analyze the effectiveness of changes that are made in M/W maintenance and prepare summaries for use of other transit properties.

TARGETS: Costs -- Provide effective support at a cost of not more than \$250,000 per year.

Time -- Initiate support work in 4 months.
 -- Provide first products within 6 months and regularly thereafter.

CONSTRAINTS: Recommendations for changes in M/W organizations, staffing and management procedures must be acceptable to the top management of transit properties. Procedures recommended for collecting, storing and analyzing track maintenance data must be compatible with other data processing programs now being developed.

SITUATION: Transit track maintenance in general is noticeably better than the average of facilities maintenance in other industries. However further improvements are needed to help offset rising costs.

The M/W superintendents who have done the most to improve the effectiveness of track maintenance are interested in further improvements, but they and their staffs do not have as much time available as they would like for investigating potential improvements, modifying them to suit local conditions and monitoring trial applications.

Under the present study, thirty-five favorable available maintenance practices have been identified, only a few of which are in fully effective use at any one transit property.

ANALYSIS:

With continuing industrial engineering support provided over a period of not less than five years, it is probable that an average improvement of at least 9% could be achieved in track maintenance effectiveness.

Projected costs and savings -- As discussed in the paragraph on overall costs and quantities, the 1979 cost of transit track maintenance and replacement in the United States is over \$60 million, and this figure can be expected to rise. An improvement of 9% in the cost effectiveness of track maintenance would provide savings of:

$$S = \$60 \times 10^6 \left(1.00 - \frac{1.00}{1.09} \right) = \$4.9 \text{ million/yr.}$$

However this level could not be reached until the second year after completion of the task. A few readily-identifiable improvements should be introduced during the first year of the task, but appreciable savings would not accrue from then until the second year. The savings would rise rapidly as potential improvements that are relatively easy to investigate and validate were put into wider practice, but the rate of increase would gradually fall as the remaining potential improvements available from existing technology would be more and more difficult to adapt to local conditions and would tend to be less and less profitable.

Costs and savings per year (in thousands of dollars) are estimated as follows:

Year	1	2	3	4	5	6	7
Costs	250	250	250	250	250		
Savings	0	300	1000	2100	3300	4400	4900
Net	-250	+50	+750	+1750	+3150	+4400	+4900

The present value (PV) of the estimated repetitive savings over a 50-year life cycle for transit systems would be:

$$\begin{aligned} \text{PV of savings} = & -250(1+i)^{-1} + 50(1+i)^{-2} + 750(1+i)^{-3} + 1750(1+i)^{-4} \\ & + 3150(1+i)^{-5} + 4400(1+i)^{-6} + 4900 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-6}}{i} \right) \\ = & \$34.0 \text{ million (rounded).} \end{aligned}$$

TASK No. 21: Investigate Inspection Practices Used by Trackwalkers and Develop Guidance on Favorable Inspection Techniques

OBJECTIVE: Provide clear information for track inspectors on what and how to inspect, using available tools and techniques.

Sub Objectives: Identify needs for improved tools and inspection techniques.

TARGETS: Cost -- Develop handbook and back-up information at a cost of not more than \$70,000.
Time -- Complete investigation, handbook and report in 1 year from the contract award.

CONSTRAINTS: Guidance on ride quality inspections is included in the task on developing a ride quality recording system. The development of guidance on track geometry measurements should be deferred pending the completion of related work by others.

SITUATION: Trackwalkers inspect track at frequent intervals and perform minor maintenance such as tightening loose bolts. The guidance they have is generalized, and they carry very few tools besides a wrench. They often miss conditions that should be reported, and do not tighten bolts or take other corrective actions that help resist deterioration of the track.

On the average, 80 trackwalkers are engaged in inspection and minor maintenance work. They usually inspect all of 1340 miles of line track twice each week and inspect yard track about once a month. Their direct pay and overhead costs amount to more than \$1.8 million per year. Improvements in the quality of their work that could be made if they were provided with the best available information on favorable inspection techniques, would not result in reduced inspection costs but in increases in the overall effectiveness of track maintenance.

Improved inspection and reporting would contribute to more effective use of track maintenance resources; so more maintenance would be done routinely at the time it is most cost-effective before it becomes emergency work with higher unit costs. Improved performance of minor maintenance by trackwalkers would result in longer useful life for track components such as bolts, fasteners and joint bars.

Even a 0.1% improvement would produce an appreciable savings:

$$\$60 \times 10^6 \left(1.00 - \frac{1.00}{1.01} \right) = \$60,000/\text{yr.}$$

Assuming that this rate would be achieved during the second year after the start of the task, the present value calculated in thousands over the 50-year life of the track would be:

$$\begin{aligned} \text{PV} &= -70(1+i)^{-1} + 60 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-2}}{i} \right) \\ &= 70 \times 1.1^{-1} + 60 \left(\frac{1-1.1^{-50}}{0.1} - \frac{1-1.1^{-2}}{0.1} \right) \\ &= \$490,000 \text{ (rounded)}. \end{aligned}$$

In addition, small improvements in the quality of inspection could be expected to be beneficial to safety and the general attitude of the M/W department.

TASK No.22: Investigate Training Requirements, Available Programs and Effectiveness.

OBJECTIVE: Define scope, costs and value of training support program.

Sub Objectives: Obtain data on costs, damage control and recovery, and training practices that will be useful in other tasks.

TARGETS: Costs -- Complete investigation and report at a cost of not more than \$30,000.

Time -- Complete all work within 8 months of contract award.

SITUATION: Track maintenance training is being conducted in-house by some of the transit properties and is considered very effective. Correspondence courses are used in some cases. Commercial training courses are available that may be very beneficial.

The requirements and benefits of track maintenance training have not been evaluated. Information is needed on which to base plans for training support that will benefit all the transit properties.

This is a preliminary task, and data is not available on which to base an analysis of its value.

TASK No.24: Develop a Ride Quality System for use in Transit Track Maintenance Planning.

OBJECTIVE: Develop a rugged, packaged ride quality system that can be used on any car on any transit system to record smoothness of the track.

Sub Objective: Develop techniques for deriving track condition and changes in track condition from ride quality data.

TARGETS: Assist transit engineers to increase the effectiveness of track maintenance a minimum of 2% by pinpointing areas that need maintenance urgently as opposed to areas in which savings can be made by deferring maintenance.

Costs -- Complete design, assemble ride quality package and train operators at a cost of not more than \$90,000.

Time -- Start field tests within 18 months.

SITUATION: It is very common to overmaintain sections of track that seem bad and undermaintain sections of track that seem relatively good but are beginning to deteriorate rapidly. Visual inspections and manual measurements do not provide sufficient data on track condition and changes in condition for making the best decisions on the most effective use of maintenance resources. While ride quality measurements will not take the place of other inspections such as visual inspections of ties and fasteners and measurements of rail wear, gage and cross level, they will provide revealing information for decisions by the M/W Superintendent who is trying to maintain the most effective balance in the use of his limited track maintenance resources.

ANALYSIS: The probability of success for this task is very high since similar ride quality systems have been developed and have worked, and since ride quality has been found to be an excellent indicator of changes in track condition.

As mentioned previously, the current cost of transit track maintenance and replacement in the United States exceeds \$60 million per year. An improvement of 2% in the efficiency of trackwork would amount to a savings of:

$$\begin{aligned} S &= 60 \times 10^6 \left(1.00 - \frac{1.00}{1.02}\right) \\ &= \$1.2 \text{ million per year.} \end{aligned}$$

These savings would begin within 18 months after the start of the task and would be repeated throughout the 50-year life cycle of the track system. Of course some of the savings will be offset by annual operating and maintenance costs for the ride quality recording system as well as the initial development costs.

Operation of the system will require the efforts of two trained technicians plus a small amount of engineering support to overcome normal problems that will arise. It is expected ride quality surveys could be performed on all line transit track in the U.S. every four months. The costs are:

36 days on track for 2 technicians and 24 days of travel for a total of 360 man-days per year.

Assuming an average loaded salary of \$45,000 per man-year means labor costs total \$67,550. Travel expenses are estimated at \$6,000; engineering support from the transit systems is 0.2 man-years @ \$65,000 per man-year which is \$13,000; maintenance and repair costs are estimated at 10% of initial costs which amounts to \$8,000. Total annual costs are therefore \$94,500.

The net savings per year is therefore

$$= \$ (1.2 - 0.095) \times 10^6$$

$$= \$1.1 \text{ million}$$

The present value of the repetitive savings over the 50-year life cycle of transit systems, starting 18 months after project approval, with interest at 10% per year is:

$$\begin{aligned} PV &= S \frac{1 - (1+i)^{-50}}{i} - S \frac{1 - (1+i)^{-1.5}}{i} \\ &= 1.1 \times 10^6 \left(\frac{1 - 1.1^{-50}}{0.1} - \frac{1 - 1.1^{-1.5}}{0.1} \right) = \$9.4 \text{ million} \end{aligned}$$

From this we have to subtract the research cost of \$90,000 and the present value of the replacement costs for the ride quality recording system throughout the 50-year life cycle of the track system.

It is assumed that, with good maintenance, the ride quality system will have a useful life of 10 years. Then the system will have to be replaced completely in 1979 + 1 + 10 and at 10-year intervals thereafter. Replacement of all the components plus assembly and check out is estimated at \$30,000 (no development costs). The present value of future replacement costs is:

$$\begin{aligned} PV &= 30,000 (1.1^{-11} + 1.1^{-21} + 1.1^{-31} + 1.1^{-41}) \\ &= \$16,700. \end{aligned}$$

The net present value of the project is therefore:

$$\begin{aligned} PV &= 9.4 \text{ million} - 90,000 - 16,700 \\ &= \$9.3 \text{ million (rounded)}. \end{aligned}$$

TASK No. 25: Investigate Practices in Making Track Available for Maintenance Work.

OBJECTIVE: Develop guidance on the most favorable practices in making track available for maintenance work.

Sub-Objectives: Identify design and construction track features that are helpful in arrangements for track availability. Identify all effects of track availability on costs and operations.

TARGETS: Assist M/W superintendents to improve maintenance productivity a minimum of one percent.

Costs--Develop effective guidance at a cost of not more than \$100,000.

Time--Complete task within a period of 10 months.

SITUATION: The time spent actually performing productive work in track maintenance is low because of the time lost in travel and start-up on small scattered jobs. Thus when track crews are also interrupted by frequent traffic, productivity is very low. Properties with older tracks and higher levels of maintenance reroute traffic during off-peak hours and close tracks completely in order to increase track availability for maintenance work. Central control of switching facilitates single track operation to make other tracks available for maintenance.

Some properties have provided temporary bus service, so that tracks could be closed completely for maintenance. While the costs of bus service were high, the value of increased productivity was said to be even higher.

ANALYSIS: The analysis of this task is similar to that for the task to develop a ride quality recording system. As estimated in the paragraph on overall costs and quantities, the current cost of track maintenance exceeds \$60 million per year. The principal investigator has found that productivity* in plant maintenance usually runs less than 50% even with good maintenance management and without interruptions by traffic. Thus an increase of 1% in productivity would be equivalent to more

*Productivity is defined as the actual performance of work on the job site. It does not include travel, assembling tools and materials, discussing the job, laying out the work, inspecting it, clean-up, reporting and other necessary support work.

than a 2% increase in maintenance effectiveness. This would help offset rising costs and would be worth:

$$\begin{aligned} S &= \$60 \times 10^6 \left(1.00 - \frac{1.00}{1.02}\right) \\ &= \$1.18 \text{ million per year} \end{aligned}$$

The savings/improvements would be repeated each year throughout the 50-year life cycle of the track. Assuming the savings would begin one year after completion of the track, their present value would be:

$$\begin{aligned} PV &= 1.18 \times 10^6 \left(\frac{1 - (1+i)^{-50}}{i} - \frac{1 - (1+i)^{-1}}{i} \right) \\ &= 1.18 \times 10^6 \left(\frac{1.1^{-1} - 1.1^{-50}}{0.1} \right) = \$10.63 \text{ million} \end{aligned}$$

The estimated cost of the task is subtracted from this, leaving a net estimated value for the task of \$10.6 million.

TASK No. 26: In-Place Treatment for Deteriorated Wood Ties.

OBJECTIVE: Extend Useful Life of Ties 10 years minimum.

Sub Objective: Treatment should be repeatable and effective at least three times before replacing tie.

TARGETS: Costs -- Develop in-place treatment technique at not more than \$100,000.
-- Treatment should cost not more than \$15.00/tie (1979 prices).
-- Train maintenance teams and conduct demonstrations at not more than \$150,000.
Time -- Begin tie treatment in 2 years.

CONSTRAINTS: Ties must be treated while they can still perform functions effectively, approximately five years before replacement would be necessary.

SITUATION: Ties on open structures. Population is 960,000 plus. The ties require replacement at an average life of 30 years because of drying, checking, retention of dust and debris in cracks, and rot. Many ties are old, and many have been replaced recently. Average age is 15 years plus. It costs about \$55 each to replace single ties at random intervals along elevated track.

Ties in ballast (surface -- including yards -- embankments and ballasted decks). Population is 1,300,000 plus. These ties require replacement at average life of 40 years. Average age is 20 years plus. It costs about \$50 each to replace single ties at random intervals along ballasted track.

ANALYSIS: Ties on open structures. Without treatment the ties need replacement every thirty years. Assuming a representative tie is 15 years old in 1979, it will need replacement at 15 and 45 years during the 50-year transit system life cycle. The present value (PV) of future costs @ 10% interest compounded annually is:

$$\begin{aligned} \text{PV} &= \text{Cost} (1+i)^{-n} \text{ years} \\ &= 55(1+0.1)^{-15} + 55(1+0.1)^{-45} \\ &= \$13.92 \end{aligned}$$

With treatment at 10 years, 20 years and 30 years and replacement at 40 years, the present value of costs would be:

$$\begin{aligned} PV &= 15 (1.1^{-10} + 1.1^{-20} + 1.1^{-30}) + 55(1.1)^{-40} \\ &= \$10.09 \end{aligned}$$

The present value of the savings would then be:

$$\$13.92 - 10.09 = \$3.83 \text{ per tie}$$

Based on a 960,000 population of ties, overall savings would be: $960,000 \times 3.83 = \$3.4 \text{ million}$.

Ties in Ballast. Without treatment, the ties need replacement every 40 years. Assuming a representative tie is 20 years old in 1979, it will need replacement 20 years from now.

$$\begin{aligned} \text{Present value of replacement costs} &= 50(1.1)^{-20} \\ &= \$7.43 \end{aligned}$$

With treatment of an average tie at 15 years, 25 years and 35 years and replacement of it after 45 years, the present value of the treatment and replacement costs would be:

$$\begin{aligned} PV &= 15(1.1)^{-15} + 15(1.1)^{-25} + 15(1.1)^{-35} + 50(1.1)^{-45} \\ &= \$6.19 \end{aligned}$$

Present value of savings/per tie = \$1.25. Based on an overall population of 1,300,000 ties, this gives an overall savings of \$1.6 million (rounded).

NOTES

The above analysis based on the average life of a tie is probably conservative. When the population of oldest ties and newest ties are considered on open deck structures, the savings are shown to be even higher. For the oldest ties, the present value of savings would be \$8.22 per tie. For the newest ties the savings would be \$1.03 per tie.

If the life cycle of a system were reduced because of changes in city planning or other causes, the relative savings obtained by treating ties and deferring tie placements would increase.

TASK No. 27: Investigate Practices Used to Reduce Wear of Rail on Curves

OBJECTIVE: Determine the most beneficial combinations of current practices to reduce wear of rail on curves.

Sub Objective: Reduce wear of transit rail on curves at least 10%.

TARGETS: Costs -- Complete study at not more than \$120,000.
Time -- Provide guidelines in 2 years.

CONSTRAINTS: Preferred combination of practices will add not more than 5% to current maintenance and/or replacement costs.

The use of flange lubricants and other techniques to reduce rail gage wear should not increase wheel wear or surface of the rail, or cause rail corrugations.

SITUATION: The rate of gage wear on the outside rails of curves is affected by the radii of curves, traffic speed and frequency, and car characteristics. Rails on very sharp curves require replacements in as little as 9 months, while rails on long-radius curves under light traffic often last more than 20 years. Of the hundreds of miles of curved transit track, over 10 miles is on curves of 300-foot radius or less. On these sharp curves, the average life of the high rail is approximately 2.5 years, and the average life of the restraining rail is approximately 4 years. The low rail lasts longer, as it is subject only to surface wear and is lightly loaded when compared to railroad rail.

Practices now used to help reduce rail wear include: gage widening, increasing superelevation, using tapered wheels, lubricating the gage side of the high rail and lubricating the flanges of the wheels, hardening the rails, alloying rail steel with other minerals, transposing the high and low rails to distribute the gage and surface wear between them, using restraining rails inside the low rails, and lubricating the restraining rails. A variety of lubricants are used.

Some studies have been made on modifying the trucks of railroad cars to make them "steerable." This eases the angle of attack of the lead wheel, as the two axles assume positions on radii of the curve rather than being held rigidly at right angles to a short-chord.

ANALYSIS:

The current replacement costs of rail on curves averages approximately \$5,000 for the high rail and \$7,000 for the restraining rail (350-foot long curve). If replaced at the same time as the restraining rail, the low rail costs about \$3,500, but because of its longer life, it is omitted from this analysis.

Sharp curves with radii ≤ 300 feet are usually less than 350 feet long, say 200 feet on the average. However the costs of rail replacement are not reduced proportionately because the costs of job preparation and lost time tend to dominate. Say the average costs of rail replacement on these sharp curves are \$4000 for the high rail and \$5600 for the restraining rail. Then the annual replacement costs would be:

$$\frac{10 \times 5280}{200} \left(\frac{4000}{2.5} + \frac{5600}{4.0} \right) = \$790,000$$

A 10% reduction in average rail wear at a 5% increase in unit replacement and maintenance costs would produce a 5% savings per year over the life cycle of the track:

$$S = \$790,000 \times 0.05 = \$39,500 \text{ per year}$$

The savings actually start two years after the research work is initiated. The present value of the repetitive savings over the 50 year life cycle of the system would then be:

$$\begin{aligned} PV &= S \frac{1 - (1+i)^{-50}}{i} - S \frac{1 - (1+i)^{-2}}{i} \\ &= 39,500 \left(\frac{1 - 1.1^{-50}}{0.1} - \frac{1 - 1.1^{-2}}{0.1} \right) = \$323,000 \end{aligned}$$

Subtracting research costs, the net present value of the task would be:

$$323,000 - 120,000 = \$200,000 \text{ (rounded).}$$

TASK No. 28: Investigate Use of Bolted and Welded Joints for Rail in Curves and Short Tangents.

OBJECTIVE: Determine the break even points on a life cycle cost basis, for rail with bolted joints (BJR) and rail with welded joints (CWR) in terms of curve radius and/or length.

Sub-Objective: Provide guidance that will help M/W superintendents to reduce the cost of maintaining curved track.

Develop a procedure and outline for the systematic consideration of all significant factors (such as clearances, access to the worksite and time available on track) in the decision process.

TARGETS: Costs: Complete the investigation and analyses at not more than \$90,000.

Time: Provide guidelines in 18 months.

SITUATION: CWR in small quantities is costly and difficult to obtain and handle when replacements are needed for worn rail in curves. In-track welds by thermite processes are also costly, and they add to the probability that rail flaws will develop.

BJR in standard lengths can be handled and bent to sharp curves easier than CWR can, and bolted joint bars can be installed in less time on track than is needed to weld joints. However bolted joints add considerably to the maintenance of ballasted track at grade and on soil embankments, where traffic vibrations and variations in the stiffness of the rail at joints increase the rate of degradation of ballast and subgrade.

Transit engineers have estimated in discussions that the replacement of CWR costs as much as 50% more than the replacement of BJR in short curves regardless of their radii. When many miles of track are replaced at one time on a railroad, the total costs for CWR are less than for BJR, and savings in maintenance (for ballasted track at grade and on embankments) have been estimated at \$1,800 to \$2,000 per year per single-track mile.

Most of the CWR installed in curves at present is on newer track systems in curves of 500-foot radius or more, and the life of the high rail in these curves is relatively long (say 8 to 10 years) depending on

traffic. Another interesting condition is that many of the curves are on concrete slabs, with direct fixation fasteners or wood block supports. In these cases, the bolted joints will not add greatly to track maintenance as they would in ballasted track at grade or on soil embankments.

NYCTA and SEPTA plan to weld a total of several hundred miles of rail in track with a flash butt weld process. This could greatly increase the quantity of CWR in curves and short tangents.

ANALYSIS: Cost data and other information collected under the present contract and available from other sources are not adequate for a cost analysis. However since there are over 100 miles of transit track in curves below 1,500 foot radius, and it is probable that over half of this could eventually be considered for the option of BJR and CWR, it is evident that information to support sound decisions would be very valuable.

TASK No. 29: Review the Relation of Transverse Wheel Tread and Flange Profile to Rail Wear, and Study Wheel Grinding Practices.

OBJECTIVE: Develop guidance for grinding wheels so as to minimize wear of rail and wheel.

Sub Objective: Assist equipment and M/W personnel to improve their mutual understanding and cooperation.
Identify any needs for detailed investigations and/or tests.

TARGETS: Costs -- Complete investigation, guidance and report at a cost of not more than \$60,000.
Time -- Complete task within 8 months of contract award.

SITUATION: Transit properties grind wheels to improve the ride quality of the cars by removing flat spots and restoring the design contour of the transverse wheel tread profile. The frequency and quality of wheel grinding may vary considerably, as the number of flat wheels observed varies greatly among transit systems.

The transverse wheel tread profile is considered to have large effects on rail wear. In particular, insufficient conicity or wheel taper contributes to flanging on curves and accelerated wear of the gage side of the high rail. The reverse curvature (false flange) that develops on the tread of worn wheels produces heavy contact pressures that contribute to head flow and corrugation of the low rail.

The literature concerning transverse wheel tread profile and its relation to wear of wheel and rail is limited. However a thorough review may reveal some opportunities for improving even the better wheel grinding practices, and study of current practices at the transit properties should assist managers to raise them to the level of the best practices.

ANALYSIS: Data has not been collected that could be used to quantify the potential benefits of this task. However since rail and wheel wear are costly problems, and the operation of cars with flat wheels contributes to the degradation of car and track components, it is considered probable that the task will provide benefits that far exceed its costs.

TASK No. 31: Investigate Corrosion of Rail and Other Track Components.

OBJECTIVE: Develop guidance on cost-effective practices to reduce corrosion of rail components.

Sub-Objective: Provide information useful to transit engineers on materials and methods for corrosion control.

TARGETS: Assist M/W superintendants to increase the effectiveness of corrosion control by a minimum of 20%.

Costs--Investigate corrosion of track components and develop guidance on effective corrosion control methods for a cost of not more than \$110,000.

Time--Complete investigation, analyses and report within 16 months of contract award.

CONSTRAINTS: Do not reduce the fire safety of the transit system or introduce materials that could produce poisonous fumes in confined spaces.

SITUATION: Corrosion is a common nuisance in transit track that adds to the maintenance work and costs. It is usually most bothersome in its attacks on small components such as bolts, that soon become difficult to clean and adjust and are often damaged beyond use. It is a serious problem when it weakens rails to the extent that they may break under traffic. The rate of corrosion depends largely on conditions at the site. It is usually bad where dripping water or wet materials ground track components to a saturated subbase. The only methods normally available to reduce the rate of corrosion of transit track components is to keep them dry and/or protect them with coatings of paint or rust-inhibiting oils.

ANALYSIS: The costs of corrosion-related maintenance work have not been kept separate from other track maintenance costs. However inspection of track conditions and discussions with M/W personnel indicate that all corrosion related work amounts to less than 0.2 of total track maintenance. This includes corrosion control, replacement of damaged components, extra cleaning of components and extra difficulties in normal track maintenance work because of corrosion. The cost of this is approximately:

$\$0.002 \times \$60 \text{ million} = \$120,000/\text{yr.}$

A 20% improvement would produce a savings of:

$120 (1.00 - 1.00/1.20) = \$20,000/\text{yr.}$

This savings or improvement would be repeated each year to help offset rising costs throughout the 50-year life cycle of the track. Assuming the savings would start the year following completion of the task, its present value would be:

$$\begin{aligned}
 PV &= 20,000 \left(\frac{1 - (1+i)^{-50}}{0.1} - \frac{1 - (1+i)^{-1}}{0.1} \right) \\
 &= 20,000 \left(\frac{1.1^{-1} - 1.1^{-50}}{0.1} \right) = \$180,000
 \end{aligned}$$

Subtracting the task costs, the net present value of the project would then be:

$$\begin{aligned}
 PV &= 180 - 110 \\
 &= \$70,000.
 \end{aligned}$$

TASK No. 32: Obtain and Develop Improved Methods and Tools for Track Inspection.

OBJECTIVE: Increase the accuracy of inspection results by providing methods and tools that are more convenient and effective than those available at present.

Sub-Objectives: Increase inspectors' interest and feeling of responsibility.

TARGETS: Costs -- Obtain and develop improved methods and tools at a cost of not more than \$120,000.

Time -- Complete study, development, and trials on track within 18 months of contract award.

CONSTRAINTS: Methods and tools should not require the assistance of a helper or a power source other than batteries carried by the trackwalker.

SITUATION: Trackwalkers inspect track at frequent intervals and perform minor maintenance such as tightening bolts. The work is difficult and time-consuming even with the best techniques and hand tools now available. Track gages and levels are cumbersome and difficult to read under poor light conditions. A trackwalker needs the help of two assistants to measure rail deviations with a stringline. He has to carry a number of small tools to do all his work properly. He should clean and probe deteriorated ties; measure rail end gap, batter and misalignment; measure wear of rails, joint bars, switch points and frogs; and check voids under ties and fastener plates.

The most favorable of the available methods and tools that a trackwalker can use in his inspection will have been identified under a prior task. Systematic study of the use of these methods and tools would indicate where improvements would be most beneficial. Review of new developments in tools and inspection methods in other industries would show where technology could be transferred effectively and where further improvements could be made. Soliciting ideas and obtaining assistance from trackwalkers and supervisors in on-site trials of new and modified tools would help raise their level of interest and enthusiasm.

As noted under task number 21, for investigation of inspection methods used by trackwalkers, this type of inspection costs approximately \$1.8 million per year. However improvements in the quality of the work would help increase the average effectiveness of track maintenance rather than reduce the cost of inspection. An improvement of even one tenth of one percent in overall track maintenance effectiveness would produce a savings or help offset rising costs by \$60 thousand/year.

Assuming this rate of improvement would be achieved within three years of the start of the task, the net present value of this small improvement, calculated in thousands, over the 50-year life cycle of the track would be:

$$\begin{aligned}
 PV &= -120x(1+i)^{-1.5} + 60 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-3}}{i} \right) \\
 &= -120x1.1^{-1.5} + 60 \left(\frac{1.1^{-3} - 1.1^{-50}}{0.1} \right) \\
 &= \$340,000 \text{ (rounded)}.
 \end{aligned}$$

In addition, small improvements in the quality of inspection could be expected to be beneficial to safety and the general effectiveness of the M/W department.

TASK No. 33: Investigate the Adjustment of Track on Elevated Structures

OBJECTIVE: Identify favorable methods for adjusting track without ballast on elevated structures and for controlling the adjustment process.

Sub-Objective: Assist M/W superintendents to reduce the cost and time required to adjust track on elevated structures.

TARGETS: Costs -- Complete investigation, develop recommendations and prepare report at a cost of not more than \$180,000.

Time -- Complete work and submit report within 2 years of contract award.

CONSTRAINTS: Equipment must be light enough to be lifted from track by two track mechanics and small enough to clear all traffic when placed on a cat walk.

SITUATION: Slight variations in the composition and strength of the materials used in elevated structures, construction tolerances and deflections under live loads, all contribute to irregularities in the track that affect ride quality and should be compensated for by precise adjustment of the track. After construction, the structure may be affected by settlement and stress-relieving movements. These movements and the wear and possible shifting of track components tend to change the smooth space curve of the adjusted track, so that additional adjustment is necessary.

Track fastened to elevated structures is more difficult to adjust than ballasted track because of the limited adjustment range of fasteners and the complexity of blocking and shimming wood ties when they are used to support the rails. Control is hampered by vibrations from passing trains and in a few cases, by vibrations from ground traffic on adjacent roads. Difficulties in controlling the adjustment of the track add to the time and cost of the work and tend to result in lower ride quality than planned for the adjusted track.

A total of over 325 single track miles of transit track is installed without ballast on elevated structures, and 90 more miles is under construction or planned. The average annual cost of maintaining the installed track is over \$12 million.

Improvements in the work of adjusting the track and the control of the adjustment process will reduce the cost of the work and help produce smoother track

which will degrade less rapidly under traffic. The net results of even a small improvement is expected to increase the effectiveness of the maintenance of elevated track by an average of at least 2%.

This will produce an annual savings or help to offset track maintenance costs by an amount equal to:

$$12 \times 10^6 \left(100 - \frac{100}{1.02}\right) = \$240,000.$$

This cost reduction will begin within four years of the start of the task and will be repeated every year over the 50-year life cycle of the track. The net present value of this repeated savings calculated in thousands would be:

$$\begin{aligned} PV &= -180(1+i)^{-2} + 240 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-4}}{i} \right) \\ &= -180 \times 1.1^{-2} + 240 \left(\frac{1-1.1^{-50}}{0.1} - \frac{1-1.1^{-4}}{0.1} \right) \\ &= \$1.9 \text{ million (rounded)}. \end{aligned}$$

TASK No. 34: Investigate the Use of Hand Tools by Trackmen and Obtain and/or Develop Improvements.

OBJECTIVE: Improve track maintenance by providing hand tools that are more effective than those now in use.

Sub-Objectives: Increase job satisfaction of track mechanics.
Encourage interest and initiative.

TARGETS: Provide accurate data to support a follow-on study of the use of portable power tools.

Cost -- Obtain and develop improved handtools for trackmen at a cost of not more than \$120,000.

Time -- Complete study development and trials on track within 18 months of contract award.

CONSTRAINTS: Tools should be easily carried and used by one man. They should not introduce or increase any safety hazards.

SITUATION: Many of the track tools now in use are heavy, cumbersome and awkward to use in confined spaces. Some are easily damaged and difficult to repair or adjust.

Systematic investigation of the use of handtools by track mechanics would indicate where improvements would be most beneficial. Review of new developments in handtools for other industries would indicate what technology could be transferred effectively and what further improvements may be feasible. Obtaining the participation of track mechanics in the project will help increase enthusiasm and interest in the quality of track maintenance work; this can be done by soliciting their ideas for improving tools and obtaining their assistance in the on-track trial and evaluation of new or modified tools.

Approximately 1200 of the people engaged in track maintenance not including trackwalkers (inspectors) use hand tools frequently in their work. At an average cost of \$22,500 each per year for direct pay, benefits and overhead, plus \$11,000 for material and equipment, they represent \$40 million of the current track maintenance costs.

Experience with military construction units has shown that small improvements in quality and productivity are readily obtained through a program to improve hand tools, especially when the program involves participation by the mechanics.

It is considered probable that an increase in productivity well over 1% can be gained within 3 years of the start of the task. This would produce a savings or help offset rising costs by \$400,000 per year. The net present value (at the time the task is completed) of this small improvement, continuing over the 50-year life cycle of the track, and calculated in thousands, would then be:

$$\begin{aligned}
 PV &= -120(1+i)^{-1.5} + 400 \left(\frac{1-(1+i)^{-50}}{i} - \frac{1-(1+i)^{-3}}{i} \right) \\
 &= -120 \times 1.1^{-1.5} + 400 \left(\frac{1-1.1^{-50}}{0.1} - \frac{1-1.1^{-3}}{0.1} \right) \\
 &= \$2.9 \text{ million (rounded)}.
 \end{aligned}$$

As in the cases of other studies of tools and methods, this study could be expected to be beneficial to the general effectiveness of the M/W department.

APPENDIX C

REPORT OF NEW TECHNOLOGY

This report describes the study of transit track conditions; current practices in track design, construction and maintenance; opportunities for improvements; available track technology; and research tasks to fill identified needs. No discoveries or inventions were made during the course of the work.

Concepts were developed for evaluating track condition, for relating track condition to transit system performance, and for evaluating research tasks.

REFERENCES

- ¹"Federal Track Safety Standards," United States Code, Title 49, Chapter 11, Part 213, Oct 1971.
- ²Manual of Railway Engineering Practices, (Fixed Properties). American Railway Engineering Association (AREA) with revisions through 1977.
- ³Portfolio of Trackwork Plans, American Railway Engineering Association, Rev. 1973.
- ⁴Cost Reduction Through Maintenance Control, Hercules Powder Co., 1964.
- ⁵"Facts and Figures 1976," New York City Transit Authority.
- ⁶Steel, R.J. and Kucera, W.J., "Rail Metallurgy Tests at Fast-Review and Update," Railway Track and Structures, May 1978.
- ⁷Prause, R.H., Meacham, H.C., Harrison, H.D., Johns, T.G., Glaeser, W.A., and Waddell, J., "Assessment of Design, Tools and Criteria for Urban Track Structures; Volume I, At-Grade Tie-Ballast Track and Volume II, At-Grade Slab Track," Battelle Reports Nos. UMTA-MA-06-0025-74-3 and -74-4, Apr & Aug 1974.
- ⁸Prause, R.H., and Harrison, H.D., "Data Analysis and Instrumentation Requirements for Evaluating Rail Joints and Rail Fasteners in Urban Track," Battelle Report No. UMTA-MA-06-0025-75-8, Feb. 1975.
- ⁹Saurenman, H.J., and Holowaty, M.C., "In-Service Performance and Costs of Methods to Control Urban Rail System Noise, Test and Evaluation Plan," Wilson, Ihrig & Associates, Inc., and DeLeuw, Cather and Co., Report No. UMTA-MA-06-0025-77-10, Apr 1977.
- ¹⁰Hanna, A.N., "Measurement Program for Evaluation of Concrete Ties and Fasteners in Transit Track," "Preliminary Specifications for..." and "Laboratory Evaluation of..." Portland Cement Assn. Reports Nos. UMTA-MA-06-0100-79-02, 3 & 8, Mar 1979.
- ¹¹"Track and Right-of-Way Characteristics for Ballasted Track-Rolling Stock Characteristics - Operating Conditions," Section V of "Technical Reference Report No. 1," APTA, Oct 1975.
- ¹²Dunn, R.H., et. al., "Trackwork Study Volume 1, Trackwork Practices of North American Rapid Transit System," DeLeuw, Cather and Co., Report No. WMATA-DLCO-TWS-1, Nov 1967.
- ¹³"Basis for Design of Track, Metropolitan Dade County, Stage I Rapid Transit System," Draft, Aug 1978.

- ¹⁴"Roster of North American Rapid Transit Cars, 1974-1976," American Public Transit Association Report No. UMTA-DC-06-0121-79-1, Jan 1977.
- ¹⁵Tsichritzis, D.C. and Lochovsky, F.H., Data Base Management Systems, Academic Press 1977.
- ¹⁶Ross, J.E., "Modern Management Information Systems," Reston Publishing Co., Prentice-Hall, 1976.
- ¹⁷Moving People Safely, Safety Guidelines for Urban Rapid Transit Systems, 3 ed., American Public Transit Association, and Chicago Transit Authority, Nov 1977.
- ¹⁸Scales, B.T., "Rolling Resistance and Track," Railway Engineering Journal, May 1973.
- ¹⁹King, F.E., "Wear at the Wheel Rail Interface," Seminar 5 Paper, Proceedings of a Workshop on Wear Control to Achieve Product Durability, Defense Documentation Center, Pub. No. AD-A0557712, 1976. p. X1-36.
- ²⁰Boyd, P.L., and Cunney, E.G., "Corrosion in Transit Track," ENSCO Technical Note No. 2-7-79, 15 June 1979.
- ²¹Cunney, E.G., "Mud Pumping," ENSCO, Inc. Technical Note No. 1-7-79, 1 June 1979.
- ²²Hetenyi, J., "Beams on Elastic Foundations," Scientific Series Vol. 16, Univ. of Michigan Press, 1942.
- ²³Clarke, C.W., "Track Loading Fundamentals," Series of seven articles, Railway Gazette, 1957.
- ²⁴Blacklock, J.R., Lawson, C.H. and Ledbetter, R.H., "Handbook for Railroad Track Stabilization Using Line Slurry Pressure Injection," Graduate Institute of Technology, Little Rock, AR and US Army Engineer Waterways Experiment Station Report No. FRA/ORD-77/30 Rev. Apr 1979.
- ²⁵Schaaf, H.L., "Investigating and Choosing Engineering Filter Fabrics," Railway Track and Structures, June 1979.
- ²⁶Reissberger, K.H., "Means and Methods to Increase Track Stability," Annual Technical Congress, American Railway Association, Chicago, IL, Mar 1974.
- ²⁷Heath, D.L., Shenton, M.J., Sparrow, F.W., and Waters, J.M., "Design of Conventional Rail Track Foundations," Proceedings, Institution of Civil Engineers, 51, Feb 1972.
- ²⁸Cunney, E.G., May, J.T. and Jones, H.N., "The Effects of Accelerated Ballast Consolidation," ENSCO Report, FRA-OR&D 76-274, Mar 1976.

- ²⁹Magee, G.M., et. al., "Stabilized Ballast Investigation," AAR Report No. DOT-FRA-ONSGT, Aug. 1979.
- ³⁰Weber, J.W., "Evaluation of Improved Track Structural Components under Sub-Arctic Conditions," Portal Cement Association, Report No. FRA/ORD-79-01, Jan. 1979.
- ³¹Miyamoto, T., Watanabe, K., and Aoki, M., "Development of Unconventional Track by JNR," Rail International, Mar 1975.
- ³²Meacham, H.C., "Non-Conventional Track Research Needs Over the Next Fifteen Years," Railroad Research Study Background Papers, Transportation Research Board, R.B. Cross Co., 1975.
- ³³Eisenmann, J., "Railroad Track Structures for High-Speed Lines," Technical Paper, 1975, Railroad Track Mechanics and Technology, Kerr, A.D., Editor, Pergamon Press, 1978.
- ³⁴Berry, J.S., "NZR's Kaimai Tunnel Nears Completion," Railway Gazette, Oct. 1977.
- ³⁵Lewis, B.T., and Marron, J.P., Editors, Facilities and Plant Engineering Handbook, McGraw-Hill, 1973.
- ³⁶Feldman, E.B., Industrial Housekeeping, Its Technology and Technique, McMillan, 1963.

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UMTA-79-41
Cunney, E. G.

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FORMERLY FORM DOT F 1700.11.1

